RE-ORDER NO. [redacted]

M-16-64-1 15 July 1964

M-16-64-1

N64 33705 (ACCESSION NUMBER)

300 (PAGES)

CR-59281 (NASA CR OR TMX OR AD NUMBER)

(THRU)

1 (CODE)

28 (CATEGORY)

FACILITY FORM 602

HEAT FLUX STUDY

15 July 1964

By: T. S. Newby, R. G. Eurich, D. Ow

Approved by: R. I. Schneyer, Manager
Space Programs
Department 51-33

Approved by: H. Cohan, Manager
Orbit Thermodynamics
Department 55-25

Approved by: L. Fried, Study Leader
Orbit Thermodynamics
Department 55-25

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Lockheed

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XEROX $ 2.00 FS

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ACKNOWLEDGMENT

We wish to acknowledge the cooperative spirit of JPL technical personnel. W. Hagemeyer, J. Plamondon, E. Christensen, and R. Jirka were particularly helpful and made possible the timely and successful conclusion of this effort.

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ABSTRACT

33705

The results of the Heat Flux Study prepared by Lockheed Missiles & Space Company are presented. The study consists of a parametric study of the heat fluxes on a satellite in the vicinity of the planet Venus and Mars, plus the development of a generalized computer program for computing the heat fluxes upon an orbiting satellite.

The parametric study shows the effect of altitude, orbit-solar incidence angle, orbit position surface orientation, surface dimensions, and surface radiation properties on the solar, albedo, and planetary heat fluxes incident on, and absorbed by, two satellite radiator surface configurations in the vicinity of Venus and Mars. The following quantities are computed for each of 20,538 combinations of the parameters (10,269 for each planet): the direct incident and total absorbed solar, albedo, and planetary heat fluxes on each satellite surface; the geometric view factors, radiation constants for visible radiation (solar and albedo flux), and radiation constants for infrared radiation (planetary flux).

The generalized heat flux program has the capability of computing the solar, albedo, and planetary fluxes incident on and absorbed by up to twenty surfaces of a sun-oriented or planet-oriented satellite in circular or elliptical orbit about any planet. The surfaces may consist of rectangles, trapezoids, and /or disks in any combination or orientation. Output from the program is heat flux vs. time on printed tape and punched cards. The capabilities of the program are considerably greater than required by contractural provision. Suggestions are made for extending the capability of the generalized computer program.

HEAT FLUX STUDY

ERRATA

1. Page 3-3, paragaph 2, line 5: Change "absorbed by each satellite surface from..." to "absorbed by each satellite surface including...".

2. Page 3-4, line 1: Change "...360 geocentric degrees. The" to "...360 geocentric degrees beyond the starting point. The".

3. Page 4-1, last paragraph, line 1: Change "<u>Albedo Flux</u>. The albedo flux accounted..." to "<u>Albedo Flux</u>. The albedo flux <u>accounts</u>...".

4. Page 4-1, last paragraph, line 3: Change "flux is accounted for..." to "flux accounts for...".

5. Page 4-5, Figure 4-1: The angle between surface 1 and surface 2 labeled "q" should be labeled "φ".

6. Page 4-5, legend: Delete "(surface)".

7. Page 5-7, line 7: Change "the FA matrix and the RADK factor, which is σ FA..." to "the $\mathcal{F}$A matrix and the RADK factor, which is $\sigma\mathcal{F}$A...". (Script F's instead of block F's.)

8. Page A-2: Replace page A-2 with the attached page A-2.

9. Page A-4: Replace page A-4 with the attached page A-4.

10. Page A-5: Replace page A-5 with the attached page A-5.

11. Pages A-7 and A-8, paragraph A.1.4, The True Elliptical Orbit Equations: Change the equations for semimajor axis, eccentricity, orbit period, eccentric anomaly, and time from periapsis to read as follows:

    Semimajor axis, radius, $A = (RA + RP + 2R_o)/2$

    Eccentricity, $E = (RA - RP)/2A$

    Orbit Period, $P = 2\pi\sqrt{A^3/R_o^2\ g_o}$

    Eccentric Anomaly, $EG = \cos^{-1}\dfrac{A-R}{AE}$

    Time from Periapsis, $T = P/2\pi\left[EG - E \sin EG\right]$

12. Page A-12, Figure A-10: Change "ILK = $\pm$: DISK" to "ILK = $\pm$2: DISK".

13. Page A-17, the P(I,J) equations: Change the equations for P(2,2) and P(2,3) to read:

    $P(2,2) = \cos\omega_s \times \cos\varphi_s + \sin\omega_s \times \sin\psi_s \times \sin\varphi_s$

    $P(2,3) = \sin\omega_s \times \cos\varphi_s + \cos\omega_s \times \sin\psi_s \times \sin\varphi_s$

14. Page A-18, line 1: Change "ILK = ± 1 (Disk)" to "ILK = ± 2 (Disk)".

15. Page A-31, line 1 of NOTE: Change "NOTE. The above absorbed fluxes are on a per unit bases..." to "NOTE. The above absorbed fluxes are on a per unit area basis...".

16. Page A-32: In column headed "Code", add "J" to line reading "DATA(J)... Surface identification...".

17. Page A-32: In column headed "Code", add "K" to line reading "DATA(K)... Location of parameters...".

18. Page A-32: In column headed "Symbol", change "DATA(J)" to "DATA(J,K)".

19. Page A-32: In column headed "Symbol", delete "DATA(K)".

20. Page A-34, last line: Change "J and K A 3 x 3 matrix, I = 22" to "J and K A 3 x 3 matrix, I = 1 to 22".

21. Page A-36, next-to-last entry in "Symbol" column: Change "KLUXS(J,K)" to FLUXS(J, K)".

22. Page B-13, paragraph 2, line 1: Change "The PERCENT ERROR indicates the finite difference..." to "The PERCENT ERROR indicates the maximum error in the finite difference...".

23. Page B-14, last line: Change " α_{min} = ... the α direction" to " γ_{min} = ... the γ direction".

24. Page B-15, Card 2: Add "$\pm$" in column 52. (DELTA may be + or -.)

25. Page B-15, Card 7: Change label of third field (columns 13-15) from "NO" to "N γ ".

26. Page B-15, last card: Change description of "VARIABLES" field from:

VARIABLES

0 (NOTHING)
MAXIMUM
ORBIT ECCENTRICITY
...
RADIATION CONSTANTS, $\sigma \mathcal{F}_{i-j} A_i$

to:

$$\text{VARIABLES} \left\{ \begin{array}{ll} 0 & \text{(NOTHING)} \\ 1 & \left\{ \begin{array}{l} \text{MAXIMUM SOLAR FLUX (SOLAR CONSTANT)} \\ \text{ORBIT ECCENTRICITY} \\ \ldots \\ \text{RADIATION CONSTANTS, } \sigma \mathcal{F}_{i-j} A_i \end{array} \right. \end{array} \right.$$

27. Page B-17, Figure B-8: Change "γ_{max}" to "β_{max}" so that β_{min} and β_{max} indicate the radius vectors and γ_{min} and γ_{max} indicate the angles.

28. Page B-18, first line: Change "α_{max} =...the α direction" to "γ_{max} =... the γ direction".

29. Page B-20, first paragraph following "ω =...", lines 2, 3, 5, and 10: Change "NVα" to "NVγ".

30. Page B-20, first paragraph following "ω =...", line 10: Change "...the α direction" to "... the γ direction".

31. Page B-20, second paragraph following "ω =...", line 2: Change "Nα" to "Nγ".

32. Page B-20, second paragraph following "ω =...", line 5: Change "Nα =...the α direction" to "Nγ =...the γ direction".

33. Page B-20, next-to-last line: Change "... α direction = (α_{max} - α_{min})/NVα" to "... γ direction = (γ_{max} - γ_{min})/NVγ".

34. Page B-22, first line: Change "... α direction = g/Nα" to "... γ direction = g/Nγ".

35. Page B-22, paragraph 2, line 1: Change "..., NVα = 3, ..., Nα = 6..." to "..., NVγ = 3,..., Nγ = 6...".

36. Page B-22, paragraph 2, line 2: Change "...NVα = 12" to "...NVγ = 12".

37. Page B-22, paragraph 2, line 3: Change "...Nα = 30" to "...Nγ = 30".

38. Page B-22, paragraph 2, line 4: "...(Nβ times Nα)(NVβ times NVα)" to (Nβ times Nγ)(NVβ times NVγ)".

39. Page B-25: Replace page B-25 with the attached page B-25.

40. Page C-4, paragraph "d.": Insert paragraph heading "e. Delta Angle" between lines 2 and 3.

41. Page C-7, last line of "<u>Block 4</u>": Change "963" to "324".

42. Page C-8, paragraph 4, line 2: Change"...ecliptic, the -X" to "...ecliptic, the -Y".

43. Page C-12: Replace page C-12 with the attached page C-12.

44. Page D-5, Figure D-4: Replace page D-5 with the attached page D-5.

45. Page D-7, Figure D-5: Replace page D-7 with the attached page D-7.

46. Page D-9, Figure D-6: Replace page D-9 with the attached page D-9.

47. **Page E-3: Delete cards 083 through 090, and insert cards R083 through R090 as follows:**

```
      ANUMB=CØSF(DELTA)                                      R083
      BNUMB=SINF(DELTA)                                      R083A
      CNUMB=CØSF(C)                                          R083B
      DNUMB=SINF(C)                                          R083C
      FNUMB=SINF(D)                                          R083D
      GNUMB=ACØSF(ANUMB*DNUMB*FNUMB-BNUMB*CNUMB)             R083E
      BETA=90.-GNUMB                                         R083F
      HNUMB=SINF(GNUMB)                                      R083G
      IF(HNUMB)34,33,34                                      R083H
   33 THE=ALPHA                                              R083I
      GØ TØ 15                                               R083J
   34 ENUMB=CØSF(D)                                          R083K
      THE=ACØSF((ANUMB*ENUMB)/HNUMB)                         R084
      ENUMB=(ANUMB*CNUMB*FNUMB+BNUMB*DNUMB)/HNUMB            R085
      IF(ENUMB)36,37,37                                      R086
   36 THE=360.-THE                                           R087
   37 THE=THE+ALPHA                                          R088
      IF(THE-360.)15,38,38                                   R089
   38 THE=THE-360.                                           R090
```

48. **Page E-9: Delete the DIMENSIØN and CØMMØN statements:**

```
      DIMENSIØN DATA (22,16),LDATA (22,16),DM1 (9409),P(22,3,3),R(3),
    1 DM2(2),A(3),NTN(57)
      CØMMØN DATA, DM1,P,R,NS,DM2,IZ,IK,A,NV,NTN,RAD,PI,DCR,RPLAN
```

and insert the DIMENSIØN and CØMMØN statements:

```
      DIMENSIØN DATA (22,16),LDATA(22,16)PØS(1000,3),ARA(1000,3),       R
    1 DM1(3409),P(22,3,3),R(3),DM2(2),A(3),NTN(57)                     R
      CØMMØN DATA, PØS,ARA,DM1,P,R,NS,DM2,IZ,IK,A,NV,NTN,RAD,PI,DCR,   R
    1 RPLAN                                                            R
```

49. **Page E-10: Delete card 029:**

```
   11 LDATA(2,2)=I                                                     029
```

and insert cards R029 through R029V:

```
   11 IF(IZ)12,12,19                                                   R029
   12 IF(I-LDATA(2,2))13,20,15                                         R029A
   13 NPN=36*(I-LDATA(2,2))                                            R029B
      NP1=NTN(37)+1                                                    R029C
      NP2=NTN(NV)                                                      R029D
      DØ14J=NP1,NP2                                                    R029E
      J1=J+NPN                                                         R029F
      DØ14K=1,3                                                        R029G
      PØS(J1,K)=PØS(J,K)                                               R029H
   14 ARA(J1,K)=ARA(J,K)                                               R029I
      GØ TØ 17                                                         R029J
   15 NPN=36*(I-LDATA(2,2))                                            R029K
```

```
      NP1=NTN(37)+1                          RO29L
      NP2=NTN(NV)                            RO29M
      DØ16J=NP1,NP2                          RO29N
      J1=NP2+1-J                             RO29Ø
      J2=J1+NPN                              RO29P
      DØ16K=1,3                              RO29Q
      PØS(J2,K)=PØS(J1,K)                    RO29R
16    ARA(J2,K)=ARA(J1,K)                    RO29S
17    DØ18J=38,NV                            RO29T
18    NTN(J)=NTN(J)+NPN                      RO29U
19    LDATA(2,2)=I                           RO29V
```

50. Page E-7: Delete cards 267 through 281, and insert cards R267 through R275 as follows:

```
230   SB=ANGLE+ALPHA                                      R267
      IF(SB-360.)238,236,236                              R268
236   SB=SB-360.                                          R269
238   ENUMB=CØSF(ØMEGA)                                   R270
      GNUMB=CØSF(SB)                                      R271
      HNUMB=SINF(SB)                                      R272
      SS=DNUMB*HNUMB                                      R273
      DING=GNUMB*FNUMB+HNUMB*ENUMB*CNUMB                  R274
      BING=GNUMB*ENUMB-HNUMB*FNUMB*CNUMB                  R275
```

51. Generalized Heat Flux Study Source Program Deck: Remove the MAIN PROGRAM and SUBROUTINE VIEW, and replace with the accompanying modified versions of the MAIN PROGRAM and SUBROUTINE VIEW. The modified versions incorporate the changes listed above in items 47-50.

$$\beta = 90. - \cos^{-1}(\cos\delta \sin i \sin\Omega - \sin\delta \cos i)$$
$$\sin\theta_p = (\cos\delta \cos i \sin\Omega + \sin\delta \sin i)/\cos\beta$$
$$\cos\theta_p = \cos\delta \cos\Omega/\cos\beta$$
$$\begin{aligned} \alpha_s &= 0 && \text{if } \cos\beta = 0 \\ &= \alpha_p + \cos^{-1}(\cos\theta_p) && \text{if } \sin\theta_p \geq 0 \\ &= \alpha_p + [360. - \cos^{-1}(\cos\theta_p)] && \text{if } \sin\theta_p < 0 \end{aligned}$$

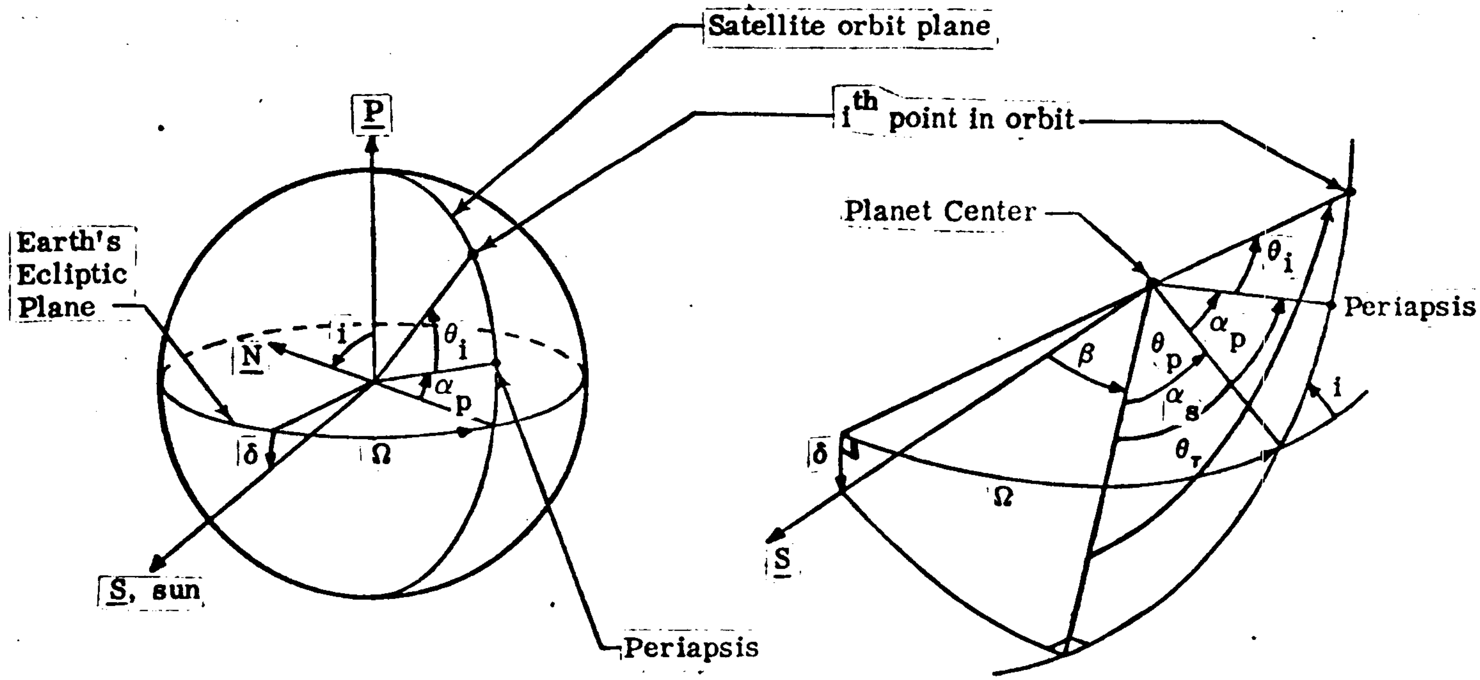

Fig. A-1 Orbit Plane

Fig. A-2 Orbit Plane Detail

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$$R(3,2) = \sin \omega_I \cos \psi_I$$

$$R(3,3) = \cos \omega_I \cos \psi_I$$

Then

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = [R] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

However, it is first necessary to define the $+Z$ axis of the sun and the planet in terms of the X'', Y'', Z'' axis depending on the orientation of the satellite.

<u>Planet-oriented satellite.</u> The $+Z$ axis is defined as follows:

Z_s = $+Z$ axis of the sun for the i^{th} satellite position

Z_p = $+Z$ axis of the planet for the i^{th} satellite position

$\theta_T = \alpha_s + \theta_i$ (see Fig. A-2)

$$Z_s = [-\sin \theta_T \cos \beta \;\; \sin \beta \;\; \cos \theta_T \cos \beta] \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

$$Z_p = Z''$$

Or, in terms of the X, Y, Z coordinate system,

$$Z_s = [(-\sin \theta_T \cos \beta)(\sin \beta)(\cos \theta_T \cos \beta)] \begin{bmatrix} R(1,1) & R(1,2) & R(1,3) \\ R(2,1) & R(2,2) & R(2,3) \\ R(3,1) & R(3,2) & R(3,3) \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Also,

$$Z_p = [R(3,1) \; R(3,2) \; R(3,3)] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

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Space-oriented satellite. The +Z axis is defined as follows:

$$Z_p = \left[\sin\sigma \;\; -\sin\Omega_T\cos\sigma \;\; \cos\sigma\cos\Omega_T\right]\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

$$Z_s = [-\sin\delta \;\; 0 \;\; \cos\delta]\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

Or, in terms of the X , Y , Z coordinate system,

$$Z_p = \left[(\sin\sigma)(-\sin\Omega_T\cos\sigma)\;(\cos\Omega_T\cos\sigma)\right]\begin{bmatrix} R(1,1) & R(1,2) & R(1,3) \\ R(2,1) & R(2,2) & R(2,3) \\ R(3,1) & R(3,2) & R(3,3) \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$Z_s = \left[-\sin\delta \;\; 0 \;\; \cos\delta\right]\begin{bmatrix} R(1,1) & R(1,2) & R(1,3) \\ R(2,1) & R(2,2) & R(2,3) \\ R(3,1) & R(3,2) & R(3,3) \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

A.1.3 Geocentric Angles of Shadow Points

As shown in Fig. A-6, a shadow point occurs when $\cos\alpha_1 + \cos Z_1 = 0$. These two unknown angles are found by an iterative process in the SHADOW subroutine.

From spherical trigonometry and identities, the following equation is developed and solved to determine the shadow points:

$$SZ = \cos(Z) = \cos\beta\cos\theta$$

$$90° < Z_1 < 270°$$

```
PERCENT TIME IN THE SUN = 100.0                    ALPHA(S) ANGLE =  321.9

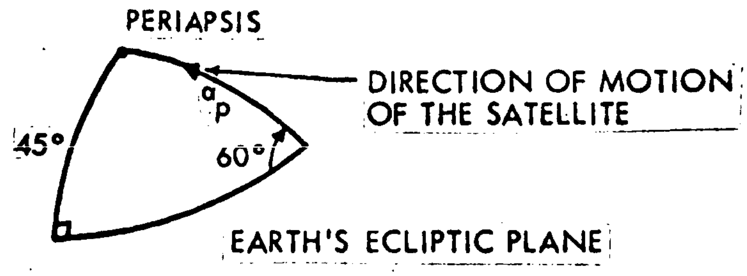
ORBIT ECCENTRICITY = C.0062                        BETA ANGLE =  -71.4

SOLAR CCNSTANT = 0.12312E-00

ORBIT PERIOC = 0.55125E 04

RADIATICN CCNSTANTS FCR VEHICLE NODES.  SPACE = NUMBER 21
K( 1, 2) =  0.
K( 2; 3) =  0.
K( 1,21) =  0.45259E-12
K( 2,21) =  0.45259E-12
```

Fig. B-13 Variables Written Out



$$\sin \alpha_p = \sin 45° / \sin 60°$$

$$\text{or } \alpha_p = \sin^{-1} \left(\frac{.70711}{.86603}\right) = 54.8°$$

Fig. C-3 Alpha (p)

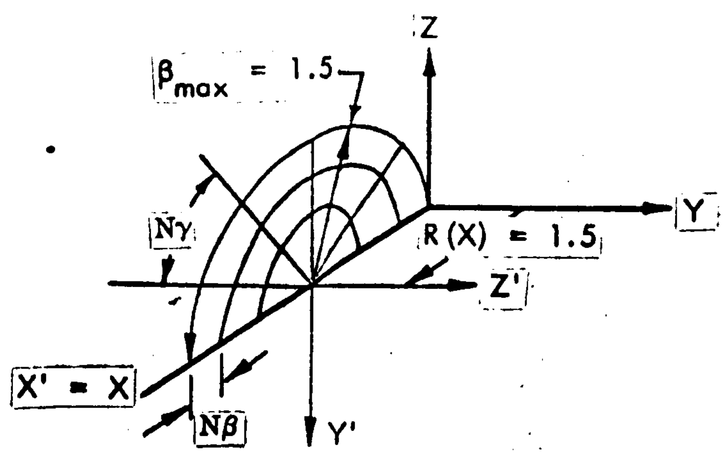


Fig. C-4 Disk

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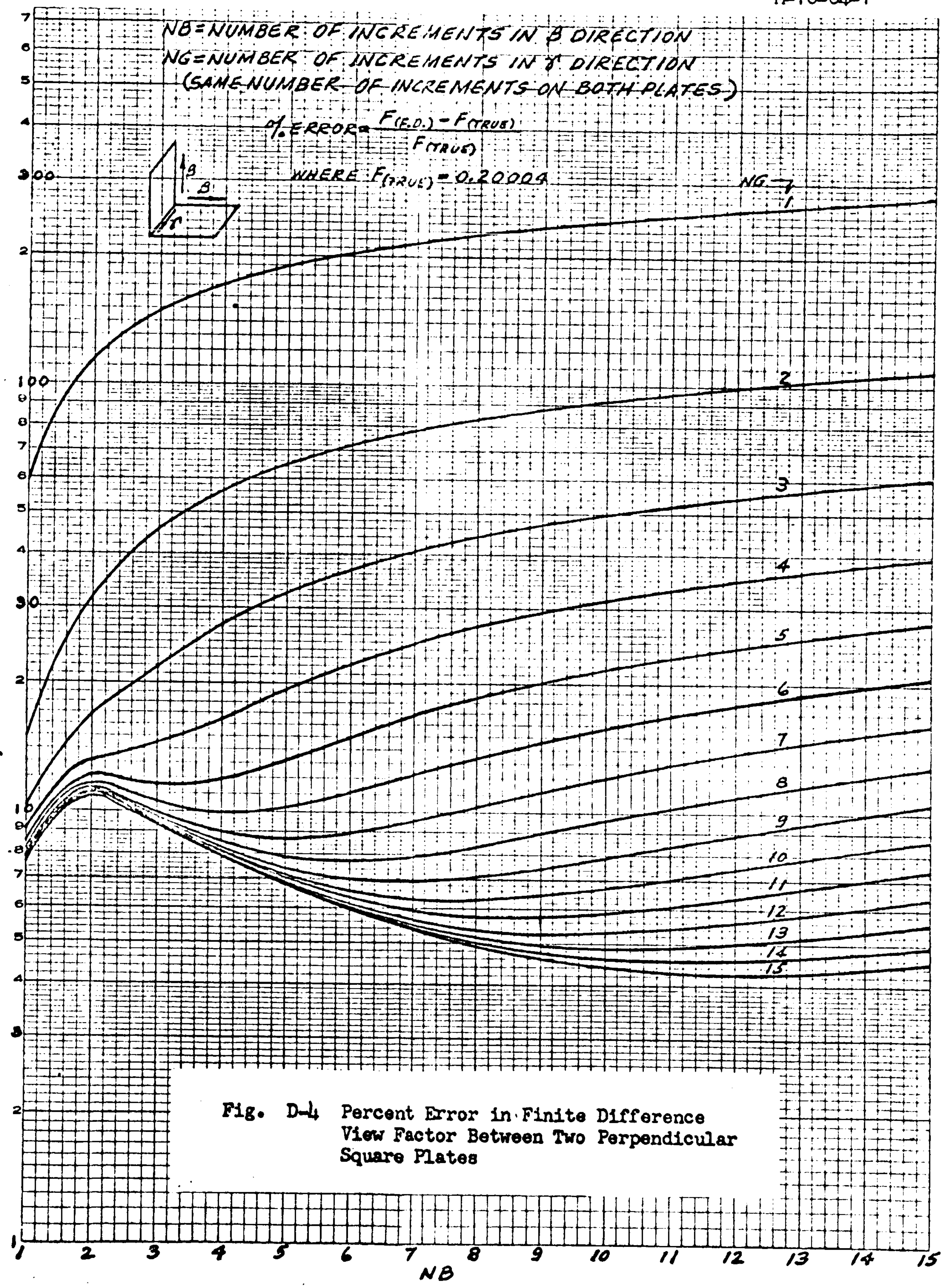

Fig. D-4 Percent Error in Finite Difference View Factor Between Two Perpendicular Square Plates

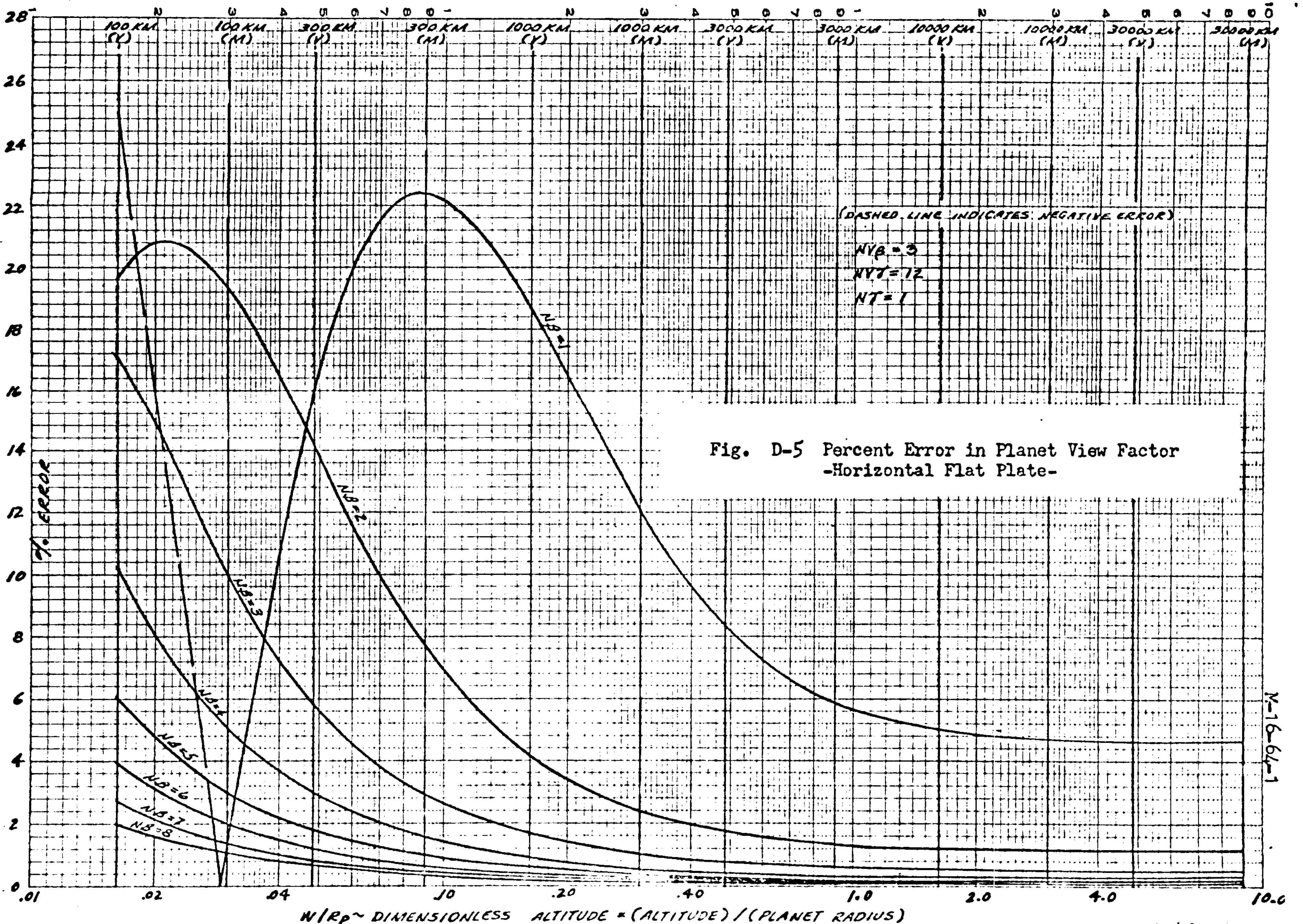

Fig. D-5 Percent Error in Planet View Factor
-Horizontal Flat Plate-

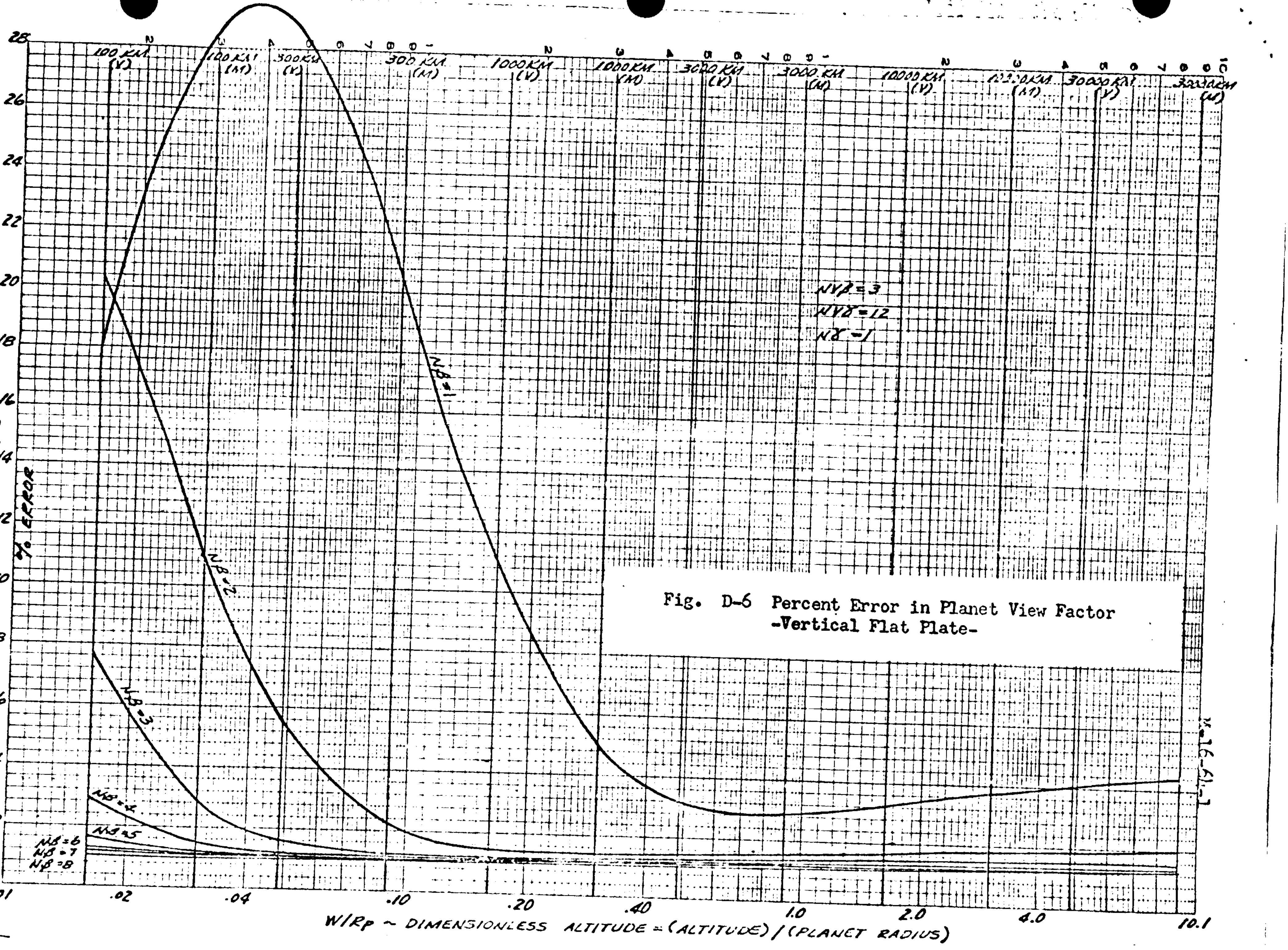

Fig. D-6 Percent Error in Planet View Factor
-Vertical Flat Plate-

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Appendix

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ILLUSTRATIONS

Figure

Figure

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Section 1
INTRODUCTION

This report was prepared by Lockheed Missiles & Space Company for California Institute of Technology, Jet Propulsion Laboratory.

Its purpose is to report the technical accomplishment of the Heat Flux Study, performed under contract number 950674, a subcontract under NASA Contract NAS 7-100.

The Heat Flux Study consists of two principal parts:

1. A parametric study to determine the heat flux incident on and absorbed by satellite radiator surfaces in the vicinity of Venus and Mars. This part includes the development of a computer program for calculation of the required data, and the performance of a number of hand calculations to provide a check on the computer program and to provide preliminary parametric information.
2. Modification of the computer program to produce a generalized heat flux computer program.

An indication of the need for this study may be obtained by considering the time that would have been required to perform the parametric study by hand calculation. The parametric study consisted of 20,538 points. The twenty-two hand calculated points performed as a check on the parametric study required an average of about one man-day per point to compute. Thus, it would have taken in the order of 80 man-years to perform the parametric study by hand. The generalized heat flux computer program will accomplish savings in time and effort of the same magnitude, permitting analyses that could not even have been attempted before.

The report is divided into six sections:

1. Introduction
2. Objectives and Scope, a brief discussion of the area covered by the study

3. Generalized Heat Flux Program
4. Parametric Study
5. Related LMSC Experience and Recommendations for Future Study
6. References

In addition to this main body of the report, there are eight technical appendixes, consisting of more detailed discussions of the major aspects of the Generalized Heat Flux Program, a description of the hand calculation techniques and results, and presentation of the Parametric Study results.

Section 2
OBJECTIVES AND SCOPE

2.1 GENERAL STATEMENT OF OBJECTIVES

The Heat Flux Study was intended to accomplish two tasks:

1. Perform a parametric study on the heat fluxes incident on, and absorbed by, satellite radiator surfaces in the vicinity of Venus and Mars
2. Develop a generalized computer program for obtaining the heat fluxes incident on, and absorbed by, a satellite of complex geometry in orbit about Venus or Mars.

2.2 PARAMETRIC STUDY

The objective of the parametric study was to show the effect of orbit altitude, orbit-solar incidence angle, orbit position, satellite orientation, satellite surface geometry, and satellite surface properties on the solar, albedo, and planetary heat fluxes on simple two-surface and three-surface satellite geometries in the vicinity of the two planets. In accomplishing this part of the study, fluxes were computed for 20,538 combinations of the above parameters, 10,269 for each planet. At each of these study points, the direct incident and total absorbed solar, albedo, and planetary fluxes were obtained for each satellite surface. In addition to the fluxes, the geometric view factors and radiation constants for visible radiation (solar and albedo), and infrared radiation (planetary) between the satellite surfaces and between the surface and the planet and the sun were also obtained. The results of the parametric study are presented in Appendixes G and H, Volumes 2 and 3 of this report. A discussion of the points calculated and the analytical techniques used is included in Section 4.

As a check on the parametric study results and to provide early parametric information, a number of points were calculated by hand. The results of these hand calculations, and the methods used, are presented in Appendix F.

2.3 GENERALIZED HEAT FLUX PROGRAM

The objective in writing the Generalized Heat Flux Program was to develop a computer program for use on the IBM 7094 capable of computing the solar, albedo, and planetary fluxes incident on, and absorbed by, a satellite in orbit about Venus or Mars. In accomplishing this part of the study, a computer program was written with the following capabilities:

1. Any set of planetary and solar characteristics may be used. Thus, the program is capable of computing the fluxes near Venus and Mars, but is not restricted to those two planets. As better information on the planetary characteristics is obtained, the program user can very easily incorporate the new information without modifying the program.
2. Any values of the orbital parameters may be used. There are no restrictions on the orbit radius, eccentricity, or orientation.
3. The satellite may be either space oriented or planet oriented.
4. The satellite may contain up to twenty surfaces consisting of rectangles, trapezoids (including triangles), and circular disks. These surfaces may be oriented in any arbitrary manner. The fluxes are computed for all of the surfaces. The increase in the number of surfaces from ten to twenty, and the addition of the disk surface configuration, represents an increase in capability over and above the proposal upon which the contract was based.
5. Shielding by the other satellite surfaces is accounted for in computing the direct incident fluxes to each surface. Shielding by and reflection from the other surfaces is accounted for in computing the total absorbed fluxes to each surface.
6. The program has the output capability of presenting all of the computed fluxes vs. time on printed tape and on punched cards. One type of output format is provided for; other formats can be added by minor program changes.

The main body of the program was written in the FORTRAN II, Version 3, language. Four subprograms, which replace certain library routines, were incorporated from previously written programs. These four subprograms were written in the FAP language. The program was designed to be run on the IBM 7090/7094 Computer Complex.

Section 3
GENERALIZED HEAT FLUX PROGRAM

3.1 GENERAL

This computer program was written to compute heat fluxes from the sun (solar), the planet's reflection of sunlight (albedo), and the long wavelength radiation from the planet (planetshine) for satellites in orbit about the planets of our solar system. This generalized heat flux program written in FORTRAN language for the IBM 7090/7094 Computer, has the following capabilities.

3.2 CAPABILITIES OF COMPUTER PROGRAM

1. Heat fluxes for up to twenty different satellite surfaces in any arbitrary relation to each other.
2. Obstructed views between satellite surfaces and the sun or planet because of intervening surfaces are accounted for.
3. The program user can omit, at his option, the subroutine that determines if there is an intervening surface or surface shading. The nonshading satellite surface configuration requires less computer run time.
4. Rectangles, disks, and triangles or any part of these geometric configurations can be handled by the program.
5. The satellite may be either space oriented or planet oriented.
6. Heat fluxes may be obtained for the entire orbit or a partial orbit starting at any initial time.
7. Up to thirty-six heat flux points may be caluclated. In addition, special heat flux calculations are made as the satellite enters and leaves the planet shadow.

8. The calculated heat fluxes are listed on tape as a function of satellite orbit time and may also be punched on IBM Card.
9. The program user is allowed to determine the set of units to be used. The program is not restricted to one basic set of units to be used in calculating the heat fluxes.
10. Any planet in our solar system may be used, as well as any planet size and surface condition.
11. Any orbit altitude and degree of eccentricity can be handled.
12. The following variables are also calculated to aid the program user in the thermal analysis of the satellite:

    a. The solar constant at the planet's distance from the sun.
    b. The percent orbit time that the satellite is exposed to direct sunlight.
    c. The orbit period and orbit eccentricity.
    d. The Beta and Alpha (S) angles which describe the orbit plane's relation to the sun.
    e. The radiation constants between the satellite surfaces and space which are used in the calculation of the radiation heat balance on the entire satellite. These are independent of satellite surface temperature and only depend upon satellite surface area, view factors, and optical surface conditions.
13. Built-in routines minimize computer run time for certain orbits as well as for certain altitudes. See Appendix A for a more detailed discussion on the operation of these routines.

The Generalized Heat Flux Program Capabilities, as listed above, are discussed in greater detail in the Appendixes of this report.

The heat fluxes which are calculated are the radiant energies received from the sun, the planet, and the planet's reflection. The associated geometric view factor, F_{1-2} (defined in the calculation of radiant heat transfer between bodies), is calculated between each exterior satellite surface and its surroundings. This view factor, or line-of-sight exposure, may be to the sun, the planet, to other satellite surfaces, or to space. For the more complex satellite surface configurations, this line-of-sight from the satellite surface to the sun or the planet may be partially or totally obstructed by an intervening satellite surface. The generalized computer program accounts for this obstructed view factor which reduces the heat fluxes from the sun and/or the planet to the obstructed surface.

The generalized program computes and prints out the direct incident radiation fluxes (solar, albedo, and planetshine) for each satellite surface. The computer also calculates and prints out, for each satellite surface, the total absorbed radiation heat flux from the three heat sources. The total absorbed heat flux is the amount of energy absorbed by each satellite surface from the reflected radiation of other satellite surfaces. The surface optical characteristics for solar, albedo, and planetshine radiation are input by the program user along with the surface location, size, and shape.

The heat flux tables, for both direct incident and total absorbed, are shown in the sample problem (Appendix C.2). These solar, albedo, and planetshine fluxes for each surface are shown as a function of the satellite orbit time. As a satellite moves around a planet, its surfaces are exposed to constantly changing heat fluxes. However, over a reasonably small portion of this orbit, the heat fluxes do not change appreciably so the fluxes are calculated every $\Delta\theta$ geocentric degrees. The present form of the computer program has the capability of making $\Delta\theta \geqq 10$ degrees for a 360-geocentric-degree orbit. As the satellite enters or leaves the planet shadow, the solar heat flux changes rapidly so the program determines the exact geometric angle at which these points occur, and computes two corresponding heat fluxes at each point. The limiting number of heat flux points input by the programmer is 36, which does not include the four heat fluxes calculated at the planet shadow points.

The satellite orbit about the planet is described in terms of angles measured from the Earth's ecliptic and the periapsis, and the altitudes of periapsis and apoapsis. Figure B-2 in Appendix B.1 shows a typical orbit and the associated angles required for inputting the program. The heat flux tables can be started at any point in the orbit and

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stopped at any following point which may or may not be 360 geocentric degrees. The satellite orbit may be circular or elliptical with the focus of the ellipse assumed to be at the planet center. The satellite may be oriented such that one satellite axis is directed toward the center of the planet at all times (planet oriented) or oriented such that one satellite axis is directed toward a point on infinite distance from the satellite (space oriented). The variable modes of satellite motion with respect to the planet are input by the program user.

The system of units used by the computer program is selected by the program user. This freedom allows the computer user to work in the system of units with which he is most familiar and also in the system of units required by the Thermal Analyzer Program* at his disposal. The units of heat, length, time, and temperature are selected by inputting the Stephan-Boltzmann Constant in the correct desired units. There are length conversion factors which are input to the program to change large length units into more usable ones found in the Stephan-Boltzmann Constant; such as miles to feet. There must, however, be some consistency in the system of units selected as explained in Appendixes B and C. This computer program does all length calculations in the Stephan-Boltzmann Constant length units.

All the physical constants such as the planet's radius, percent albedo, effective planet surface temperatures, the effective sun radius, and temperatures are treated as input by the program so that more accurate values of these constants can readily be input by the program user as they become available. The planet distance to the sun and the angle the sun vector makes with the Earth's ecliptic plane are tabulated as heliocentric coordinates in ephemeris reference books for each day of the year for many years in the future. The inputting of all physical constants by the program user not only lets the program user select the system of units but also the solar system and a planet in the solar system provided the constants for another star and its planet are known.

Physical constants which are calculated by the program are written out in addition to the heat flux tables. These are:

*The Thermal Analyzer solves transient and steady-state heat transfer problems using the IBM 7094 digital computer to obtain a finite difference solution for the analogous A-C electrical network.

1. The solar constant at the planet distance from the sun. This will provide a valuable check on the input variables and their system of units.
2. The orbit period and eccentricity. This will check the consistency of the input data.
3. The percent time that the satellite is exposed to direct sunlight. This has been found to be a controlling factor in the mean satellite temperature level.
4. The radiation constant, C, used in radiation heat transfer, is also calculated and printed out for all satellite surfaces, where C is used in the equation $q_{1-2} = C\,(T_1^{\,4} - T_2^{\,4})$.

3.3 LIMITATIONS OF COMPUTER PROGRAM

The generalized Heat Flux Computer Program, while being extremely versatile, does have some restrictions on the input variables and on the type of heat fluxes that can be produced. The following is a summary of these limitations:

1. The length unit in which the computer operates causes a limitation on the distance between the planet and the sun before computer "overflow" (numbers $> 10^{38}$) occurs. The present form of the program is such that it will be able to calculate heat fluxes at the planet Mars at aphelion with the centimeter as the smallest unit of length.

   For the "outer" five planets in our solar system, the basic unit of length must not be smaller than the foot. These units of length, input in the Stephan-Boltzmann Constant, are the units of length output in the direct incident heat flux tables.

2. All spacecraft surfaces cannot adequately be described by rectangles, disks, and triangles (or trapezoids).

3.4 APPROACH TO THE CALCULATIONS

The basic approach to calculation of the heat fluxes is best described by the chronological programming of the problem that the program user and the computer program will use.

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The position and distance of the sun relative to the planet is obtained from planet ephemeris data for the approximate date that the heat flux on the satellite is desired. The planet radius, albedo, and temperatures (dark side and subsolar) are obtained and input in the proper corresponding system of units. The satellite orbit parameters and the satellite orientation in this orbit are specified by the program user, i.e., is it planet oriented or space oriented. Now the satellite surfaces must be built on the Surface Coordinate System (X' , Y' , Z') relative to the Central Coordinate System (X , Y , Z), as shown in Appendix B. The initial satellite orientation and other computer program flags are also input by the program user.

The computer takes the above input information, written out on IBM cards, and proceeds to calculate the heat fluxes by completing the following steps:

1. Determine the position of the planet and the sun relative to the Central Coordinate System for each point in the orbit as the satellite moves around the planet.
2. At each of these points in orbit, the geometric view factors between each surface, the planet, the sun, and other surfaces are calculated. The finite difference method of calculating view factors is used. Incorporated in this finite difference approach is a routine that checks for an intervening satellite surface. These methods are outlined in more detail in Appendix A.
3. The radiation interchange factor, K, is calculated from the matrix form of the radiant interchange equations between each pair of surfaces. These equations use the surface areas, absorptivities, and the calculated geometric view factors, and account for the reflected radiation from adjacent satellite surfaces. The matrix system of equations is solved for each source of radiation; solar, albedo, and planetshine. These equations are shown in detail in Appendix A.2.

   The K value between the sun and each satellite surface is multiplied by the Stephan-Boltzmann Constant and the sun temperature to the fourth power to become the total absorbed solar heat flux. The K value between the i^{th} planet node and each satellite surface is multiplied by the emissive power of the i^{th} planet node. The products of the 36 planet nodes and their corresponding K values are added to give the total absorbed planet shine heat flux.

The emissive power of the i^{th} planet node contains the Stephan-Boltzmann constant and the fourth power of the i^{th} planet node temperature.

The K value for the total absorbed albedo heat flux contains the geometric view factors between the sun and the planet nodes as well as between the planet nodes and the satellite surface. This K value is then multiplied by the albedo fraction, the fourth power of the sun's temperature, and the Stephan-Boltzmann Constant.

The direct incident heat fluxes are obtained directly from the geometric view factor and the emissive power of the radiation source.

4. All the heat fluxes and their corresponding orbit times are stored, to be written out when the last point in the orbit is calculated. The percent time that the satellite is in the sun and the solar constant are also calculated at this time.

The input data are broken down into five blocks, each of which contains data pertinent to a specific group of input variables, such as planet data, orbit parameters, satellite orientation, and satellite surfaces. If additional heat fluxes are desired after the initial case is run, a "restart" can be run by inputting only those input blocks that have been changed.

Section 4
PARAMETRIC STUDY

A parametric study was performed to determine the incident and absorbed solar flux, reflected solar flux (referred to here as albedo flux), and planetary flux on a system of satellite surfaces in the vicinity of Venus and Mars. A total of 20,538 points were calculated, 10,269 for each planet. The results are presented in two volumes accompanying this report.

4.1 SCOPE

4.1.1 General Requirements

The parametric study was performed under certain general conditions.

Planetary Properties. Planetary properties were as follows:

	Venus	Mars
Planet radius (km)	6,200	3,335
Planet albedo	0.73	0.15
Planet sub-solar surface temperature (°K)	235	300
Planet dark-side surface temperature (°K)	235	200

Albedo Flux. The albedo flux accounted for the variation of the intensity of reflected sunlight over the illuminated part of the planetary surface. The planetary and albedo flux is accounted for the variation in intensity over the visible portion of the planetary surface.

Values Obtained. The following values were obtained for each point calculated:

- Incident Direct Solar Flux to all surfaces. (This will be referred to as Direct Solar Flux. It is the solar flux directly incident on the surface, not including reflections from the planet or from other surfaces.)
- Absorbed Direct Solar Flux to all surfaces. (This will be referred to as Absorbed Solar Flux. It includes reflections from other surfaces but not from the planet.)
- Incident Reflected Solar Flux to all surfaces. (This will be referred to as Incident Albedo Flux. It is the solar flux reflected from the planet onto the surface, not including reflections from other surfaces.)
- Absorbed Reflected Solar Flux to all surfaces. (This will be referred to as Absorbed Albedo Flux. It is the solar flux reflected from the planet onto the surface, and includes reflections from other surfaces.)
- Incident Planetary Flux to all surfaces. (This is the flux emitted by the planet, incident upon the surface. It does not include reflections from other surfaces.)
- Absorbed Planetary Flux to all surfaces. (This is the flux emitted by the planet and absorbed by the surface. It includes reflections from other surfaces.)
- Geometrical Shape Factors. (This includes all shape factors, surface-to-surface, surface-to-planet, surface-to-sun, and planet-to-sun.)
- Radiant Interchange Factors. (This includes all interchange factors, surface-to-surface, surface-to-planet, and surface-to-sun, for solar flux, albedo flux, and planetary flux.)

Flux Sources. The three flux sources (solar, albedo, and planetary) were analyzed separately. That is, a variation in the intensity of any of the three types of flux did not affect the intensity of the other two.

Temperature and Radiation. The temperature of the satellite surfaces, and the radiation from the surfaces were not considered. The computed fluxes included only the

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fluxes incident upon the surfaces, originating in the sun or planet.

Incident Fluxes. Incident fluxes included the effect of shadowing by other surfaces, but did not include reflections from other surfaces. Absorbed fluxes included shadowing by, and reflections from, other surfaces.

4.1.2 General Assumptions

Certain general assumptions were made.

Planetary and Solar Properties. The following properties were assumed:

	Venus	Mars
Distance to sun (km)	108×10^6	228×10^6
Solar temperature (°K)	5,808	5,808
Stephan-Boltzman constant, σ (Btu/hr-ft^2-°K)	1.7993×10^{-8}	1.7993×10^{-8}
Solar diameter (km)	1.3906×10^6	1.3906×10^6

This combination of solar temperature, solar diameter, and σ produce a solar constant for earth of 442.9 Btu/hr-ft^2 or 0.123 Btu/sec-ft^2 at an earth-sun distance of 149×10^6 km.

Emission and Reflection. Perfectly diffuse emission and reflection were assumed for all surfaces, including sun and planets.

Temperature. The planet surface temperature on the illuminated side of the planet was assumed to vary as the cosine of the angle from the planet-sun line. That is, the temperature of a point on the illuminated surface of the planet is $T = T_{(\text{dark side})} + \left(T_{(\text{subsolar})} - T_{(\text{dark side})}\right) \times \cos\lambda$, where λ is the angle between the planet-sun line and the line joining the planet center and the point on the surface. The temperature on the dark side of the planet was assumed to be uniform.

Absorptivity. The absorptivity of the satellite surfaces was assumed to be the same for both solar and albedo flux, and equal to the solar absorptivity (α_s). The absorptivity of the satellite surfaces for planetary flux was assumed to be equal to the low-temperature emissivity of the surface (ϵ). Both α and ϵ were assumed to be independent of surface temperature.

Orbit. The satellites were assumed to be in idealized polar orbits. The north and south poles of the planet were assumed to be located on the terminator, a sharp line dividing the illuminated and dark sides of the planet.

4.1.3 Calculation Points

The parametric study is in two parts. Part 1, which consists of 9936 points per planet, is the main body of the study. Part 2, which consists of 333 points per planet, shows the effect of varying some of the parameters that were held constant in Part 1. Each point of the study was determined twice, once for a satellite in the vicinity of Venus, once for a satellite in the vicinity of Mars.

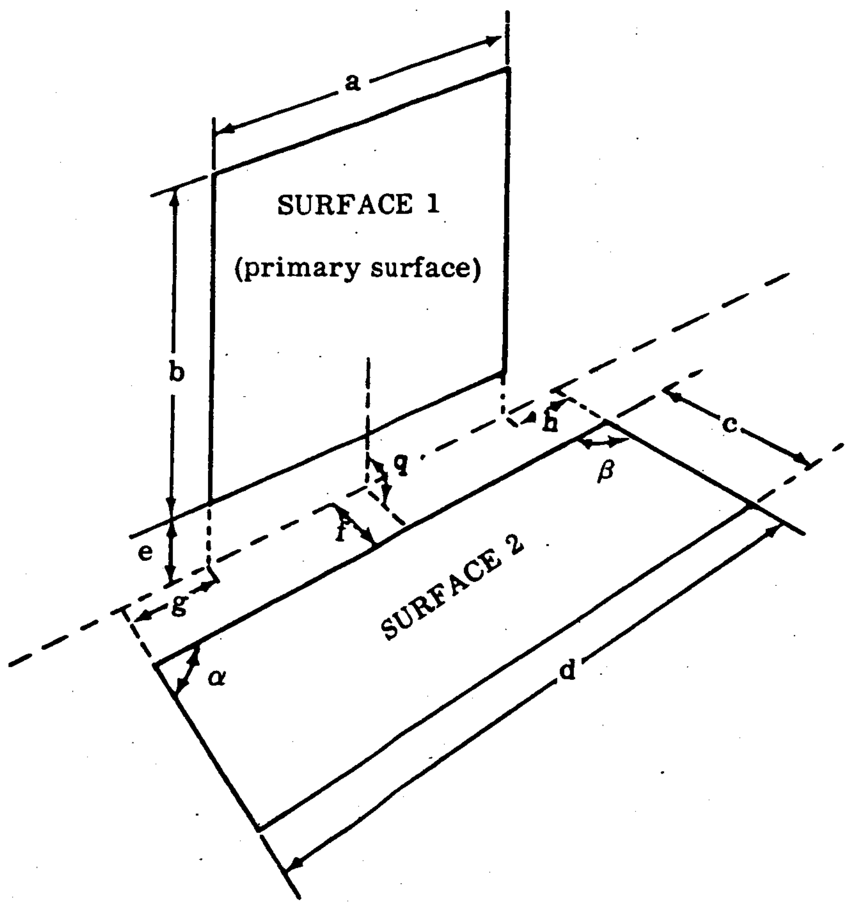
Part 1

This part of the study was characterized by the following parameters:

- Surface configurations. Two surface configurations were considered. Configuration 1a consisted of two surfaces; configuration 1b consisted of three surfaces (see Fig. 4-1).

The following geometric parameters, shown in Fig. 4-1, were held constant throughout part 1:

$$\varphi = 90°$$
$$\alpha = \beta = 90°$$
$$e = f = g = h = o$$



This is Configuration 1a. Configuration 1b contains an additional surface (surface) directly opposite surface 2.

Fig. 4-1 Surface Orientation

The geometric parameter a/b was varied over the range a/b = 1/4, 1/2, 1 for each position, orbit, orbit position, orientation, and altitude specified below. The geometric parameter c/b was varied over the range c/b = 1/4, 1/2, 1 for each a/b ratio and for each position, orbit, orbit position, orientation, and altitude specified below. (On configuration 1b, the c/b ratios for surfaces 2 and 3 were varied together.)

- Surface properties. The radiation properties of the surfaces were as follows:

  Surface 1: $\alpha_s = 0.25$, $\epsilon = 0.85$

  Surface 2: $\alpha_s = 0.96$, $\epsilon = 0.90$

  Surface 3: $\alpha_s = 0.96$, $\epsilon = 0.90$ (configuration 1b only)
- Orientation, orbit, and position. The surfaces were sun-oriented and planet-oriented, in noon polar orbit, 45-deg polar orbit, and twilight polar orbit, and in three positions relative to the orbit plane, in the combinations shown in Fig. 4-2.
- Orbit position. Eight orbit positions were considered for each combination of orientation, orbit, and position shown in Fig. 4-2, except for configuration 1b (planet-oriented, twilight orbit, positions 1 and 3), for which only one orbit position was considered. The orbit positions are shown in Fig. 4-3.
- Altitude. Fluxes at each of the foregoing combinations of points and configurations were computed at eight altitudes: 100 km, 300 km, 500 km, 1,000 km, 3,000 km, 5,000 km, 10,000 km, and 30,000 km.
- Number of points. For each planet, fluxes were computed for 3 a/b ratios × 3 c/b ratios × 8 altitudes × (8 orbit positions × 17 orbit-orientation-position combinations + 1 orbit position × 2 orbit-orientation-position combinations) for a total of 9,936 points per planet.

Part 2

The following additional points were computed at an altitude of 1,000 km, at orbit position 4 of a noon polar orbit (subsolar point), and with $\varphi = 90°$, e = f = g = h = o:

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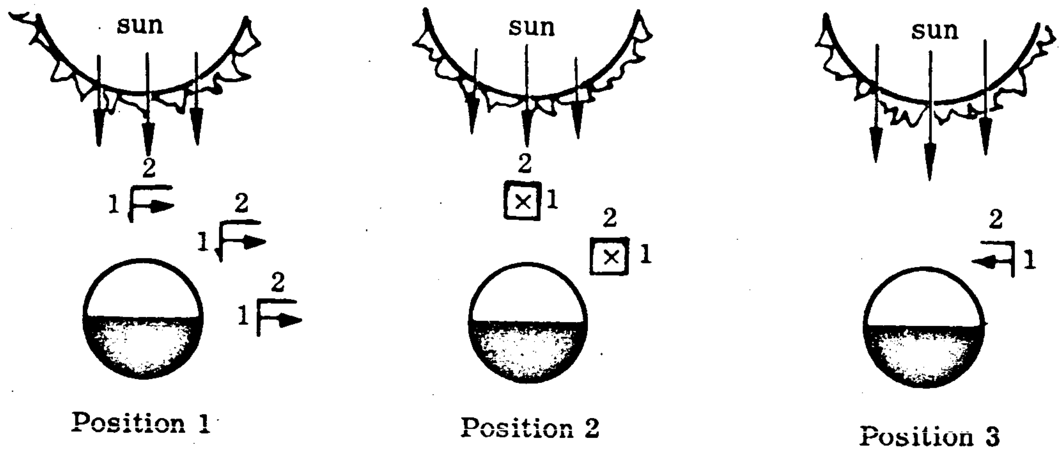
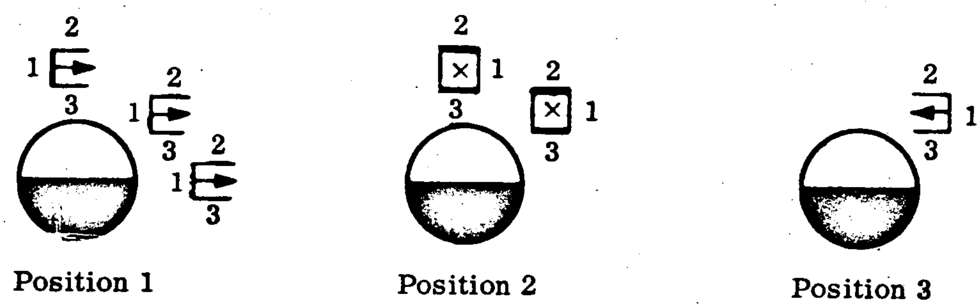
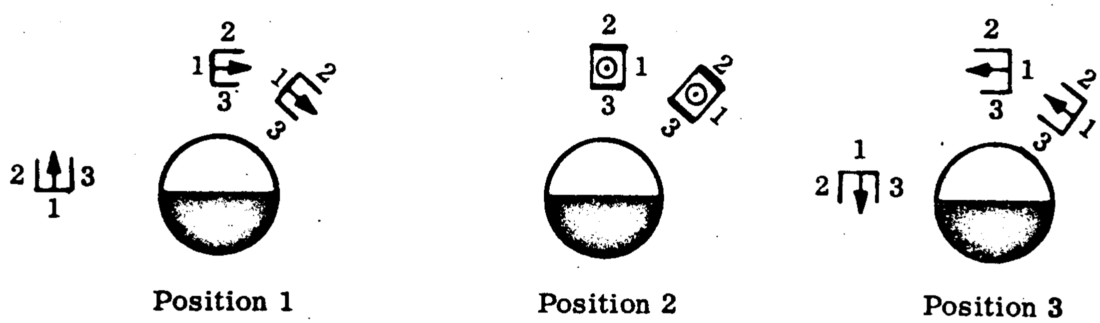


(a) Configuration 1a, sun-oriented



(b) Configuration 1b, sun-oriented



(c) Configuration 1b, planet-oriented

LEGEND: → Unit normal to surface 1 in plane of paper
× Unit normal to surface 1 into paper
⊙ Unit normal to surface 1 out of paper

NOTE: View is looking down on north pole at planet. Surfaces are shown at orbit Position 4

Fig. 4-2 Orientations, Orbits, and Positions

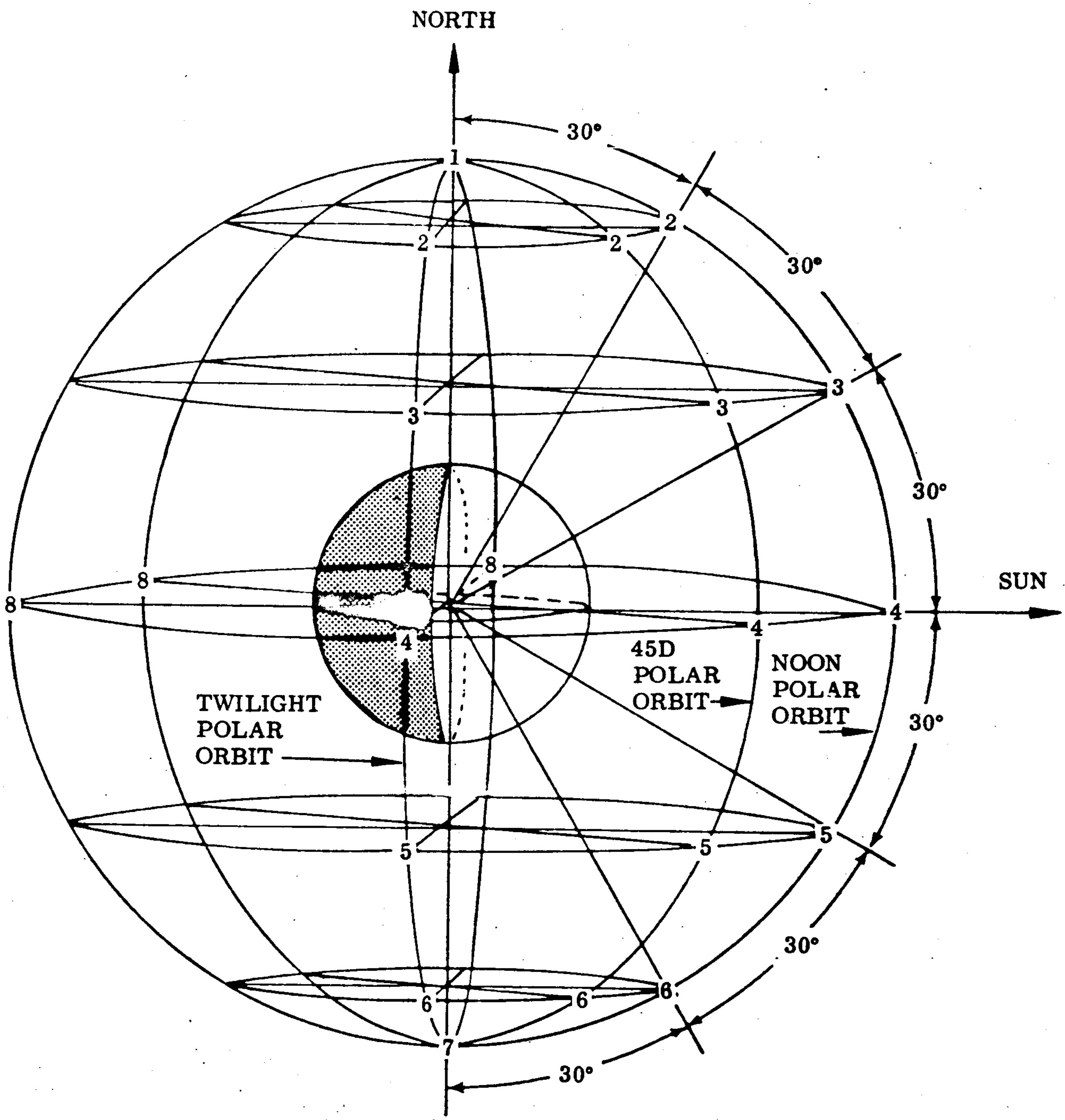


Fig 4-3 Orbit Positions

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- With α_s and ϵ as defined in Part 1 (surface properties), and with $\alpha = \beta = 90°$, a/b, c/b (surface 2), and c/b (surface 3) were varied separately over the following ranges, on configuration 1b:

  a/b = 1/4, 1/2, 1
  c/b = 1/4, 1/2, 1 (surface 2)
  c/b = 1/4, 1/2, 1 (surface 3)

  The total, then, consisted of 3 a/b's × 3 c/b's (surface 2) × 3 c/b's (surface 3) for 27 points per planet.
- On configurations 1a and 1b, with the combinations of a/b and c/b specified in Part 1 (surface configurations), and with $\alpha = \beta = 90°$, α_s and ϵ for the primary surface (surface 1) were varied over the range α_s/ϵ = 0.25/0.85, 0.30/0.30, 0.20/0.04, and 0.96/0.90; and for each of these values α_s and ϵ of the secondary surface(s) (surface 2 or surfaces 2 and 3 together) over the range α_s/ϵ = 0.25/0.85, 0.30/0.30, 0.20/0.04, and 0.96/0.90. The total consisted of 4 α_s/ϵ (surface 1) × 4 α_s/ϵ (surfaces 2 and 3) × 3 a/b's × 3 c/b's × 2 configurations, for 288 points per planet.
- On configurations 1a and 1b, with the combinations of a/b and c/b as specified in the previous item, and the α_s and ϵ values as specified in Part 1 (surface properties), the setting $\alpha = \beta = 120°$ was made. The total consisted of 3 a/b's × 3 c/b's × 2 configurations, for 18 points per planet.

4.2 METHOD OF CALCULATION

The method of calculation was essentially the same as the method of the Generalized Heat Flux Program, with certain modifications to take advantage of the restrictions imposed by the parametric study requirements.

The computer program developed for the parametric study consists of thirteen subprograms (subroutines and functions): MAINP, TRANS, VIEW, VECTOR, OMEGA, SHADE, FLUX, INVERT, OUTPUT, TAN, ATAN, TRIG, and AFUN. Of these, INVERT, TAN, ATAN, TRIG, and AFUN are identical to the respective subprograms of the generalized program. VIEW, VECTOR, OMEGA, SHADE, and FLUX are mathematically equivalent to the respective subprograms of the generalized program, although some changes have been made to take advantage of the more restricted requirements of the parametric study. MAINP and OUTPUT are changed completely. TRANS has no direct equivalent in the generalized program, while SHADOW in the generalized program is not required here.

The succeeding paragraphs describe each of the Parametric Study Program subprograms, and in particular the points of difference between the subprograms of the Parametric Study Program and those of the Generalized Heat Flux Study Program.

4.2.1 Input

For the purpose of inputting the parameters to the computer, each parameter was assigned an ID number as follows (see Figs. 4-1, 4-2, 4-3):

Input ID No.	Internal ID No.	Symbol	Parameter
0	–	–	Planet and orientation parameters
1	1	h	Altitude
2	2	β	Orbit (noon, 45-deg, or twilight)
3	3	θ	Orbit position (angle from point in orbit nearest planet-sunline)
4	4	φ_p	Primary surface φ angle at orbit position 4
5	5	ψ_p	Primary surface ψ angle at orbit position 4
6	6	ω_p	Primary surface ω angle at orbit position 4
7	7	b	Height of primary surface (input as 4 ft)
8	8	a/b	Width-to-height ratio of primary surface
9	9	α_{s1}	Solar absorptivity of primary surface
10	10	G_1	Emissivity of primary surface
101	11	$(c/b)_2$	Height-to-b ratio of surface 2
102	12	$(g/b)_2$	Width parameter of surface 2

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Input ID No.	Internal ID No.	Symbol	Parameter
103	13	$(e/b)_2$	Distance ratio of surface 2 to plane at primary surface
104	14	$(f/b)_2$	Distance ratio of primary surface to plane at surface 2
105	15	α_2	Trapezoid angle at surface 2
106	16	φ_2	Angle between plane of surface 2 and plane at primary surface
107	17	α_{s2}	Solar absorptivity at surface 2
108	18	G_2	Emissivity of surface 2
201	19	$(c/b)_3$	Height-to-b ratio of surface 3
202	20	$(g/b)_3$	Width parameter of surface 3
203	21	$(e/b)_3$	Distance ratio of surface 3 to plane of primary surface
204	22	$(f/b)_3$	Distance ratio of primary surface to plane of surface 3
205	23	α_3	Trapezoid angle of surface 3
206	24	φ_3	Angle between plane of surface 3 and plane of primary surface
207	25	α_{s3}	Solar absorptivity of surface 3
208	26	G_3	Emissivity at surface 3

The study was divided into 28 sections as shown in Table 4-1. Sections 1, 7, 19, 21, 23, 25, and 27 were run as "new cases," each of which consisted of two parts, an "equivalence list" and a "variable list." The remaining sections were run as "restart," each of which consisted of one part, modifications to the "variables list" of the preceding case.

Equivalence List. Each card of the equivalence list contained the ID Nos. of two variables which were to be varied together. For example, in Section 7 of Table 4-1 the c/b ratios of surfaces 2 and 3 were kept the same throughout the run. Whenever $(c/b)_2$ was changed, $(c/b)_3$ also had to be changed. Thus the equivalence list for Section 7 is

201 101

Similarly, the equivalence list of Section 21 is

10	9
201	101
108	107
207	107
208	107

The equivalence list was ended by a card containing a - 1 in the position of the first column of ID Nos.

Variable List. Each card of the variables list contained the ID No. of a parameter and up to eight values for the parameter. If fewer than eight values of the parameter were listed, the last value was followed by a value of $1. \times 10^{32}$. For example, the card for θ = orbit position angle (ID No. 3) was

3 -90. -60. -30. 0. 30. 60. 90. 180.

This lists in order, the eight orbit positions shown in Fig. 4-3. The card for the $(f/b)_2$ ratio (ID No. 104) was

104 0. 1.E32

since $(f/b)_2$ is held equal to 0. throughout the parametric study, and the 1.E32 signifies that fewer than eight values are listed.

The card for ID No. 0 (planet and orientation parameters) was somewhat different. It contained three quantities: the ID No. (0), a planet ID No. (1. = Venus, 2. = Mars), and an orientation flag (1. = sun-oriented, 2. = planet-oriented). The ID No. 0 card for section 13 (Venus, planet-oriented) was

0 1. 2.

The planetary parameters for Venus and Mars were built into the program; all that was required on input was to select the planet involved.

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Table 4-1

SECTIONS OF STUDY

Part 1

Section No.	Config.	Case Orient.	Planet	Orbit	Vary (in order shown)
1	1A	Sun	Venus	Noon	c/b, a/b, Alt , Orbit Pos., Posit.
2	1A	Sun	Venus	45 D	c/b, a/b, Alt, Orbit Pos., Posit.
3	1A	Sun	Venus	TWI	c/b, a/b, Alt, Orbit Pos.
4	1A	Sun	Mars	NOON	c/b, a/b, Alt, Orbit Pos., Posit.
5	1A	Sun	Mars	45 D	c/b, a/b, Alt, Orbit Pos., Posit.
6	1A	Sun	Mars	TWI	c/b, a/b, Alt, Orbit Pos.
7	1B	Sun	Venus	NOON	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
8	1B	Sun	Venus	45 D	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
9	1B	Sun	Venus	TWI	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos.
10	1B	Sun	Mars	NOON	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
11	1B	Sun	Mars	45 D	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
12	1B	Sun	Mars	TWI	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos.
13	1B	Planet	Venus	NOON	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
14	1B	Planet	Venus	45 D	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
15	1B	Planet	Mars	NOON	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
16	1B	Planet	Mars	45 D	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos., Posit.
17	1B	Planet	Venus	TWI	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos.
18	1B	Planet	Mars	TWI	$[(c/b)_3, (c/b)_2]$, a/b, Alt , Orbit Pos.

[x, y] indicates that variable

Part 2

Section No.	Case Config.	Case Planet	Vary (in order shown)	
19	1B	Venus	$(c/b)_3$, $(c/b)_2$, a/b	
20	1B	Mars	$(c/b)_3$, $(c/b)_2$, a/b	
21	1B	Venus	$[(\alpha_s/\epsilon)_3, (\alpha_s/\epsilon)_2]$, $(\alpha_s/\epsilon)_1$, $[(c/b)_3, (c/b)_2]$, a/b	
22	1B	Mars	$[(\alpha_s/\epsilon)_3, (\alpha_s/\epsilon)_2]$, $(\alpha_s/\epsilon)_1$, $[(c/b)_3, (c/b)_2]$, a/b	
23	1A	Venus	$(\alpha_s/\epsilon)_2$, $(\alpha_s/\epsilon)_1$, c/b, a/b	
24	1A	Mars	$(\alpha_s/\epsilon)_2$, $(\alpha_s/\epsilon)_1$, c/b, a/b	
25	1B	Venus	$[(c/b)_3, (c/b)_2]$, a/b	$\alpha = \beta = 120°$
26	1B	Mars	$[(c/b)_3, (c/b)_2]$, a/b	$\alpha = \beta = 120°$
27	1A	Venus	$[(c/b)_3, (c/b)_2]$, a/b	$\alpha = \beta = 120°$
28	1A	Mars	$[(c/b)_3, (c/b)_2]$, a/b	$\alpha = \beta = 120°$

x and y are varied together

The variables list was ended by a card containing a negative number in the ID No. column. This number indicated whether a "new case" or "restart" was to follow the current case, as follows:

Number	Action
-1	"New case" follows
-2	"Restart" follows
-3	Nothing follows (unload output tapes and call EXIT)

New Case. As indicated above, each new case consisted of an equivalence list, ended by a a - 1 card, and a variables list, ended by a - N card. The variables list must contain one and only one card for each parameter.

Restart. On restarts, the equivalence list (including the -1 card) was omitted. The equivalence list remained the same as it was on the preceding run. The variables list contained cards only for the parameters that were to be varied in a different manner, or whose values had been changed. For example Section 2 of Table 4-1 was run as a restart of Section 1. Only the orbit and the number of surface positions were changed – the orbit from noon to 45 deg. and the number of positions from two to three (see Fig. 4-2). Thus, only the cards for ID Nos. 2 and 4 were required.

4.2.2 MAINP Subroutine (See Flow Chart, Fig. 4-4)

Purpose. MAINP reads in input data; performs incrementation of parameters; and maintains a list of the current values of the parameters and a list of the values used in the preceding run.

Input. The following quantities are read in from the input tape:

- NOR: Orientation flag (1 = sun-oriented, 2 = planet-oriented)
- NP(I): List of variable ID's, in the order input
- NPLAN: Planet ID No. (1 = Venus, 2 = Mars)

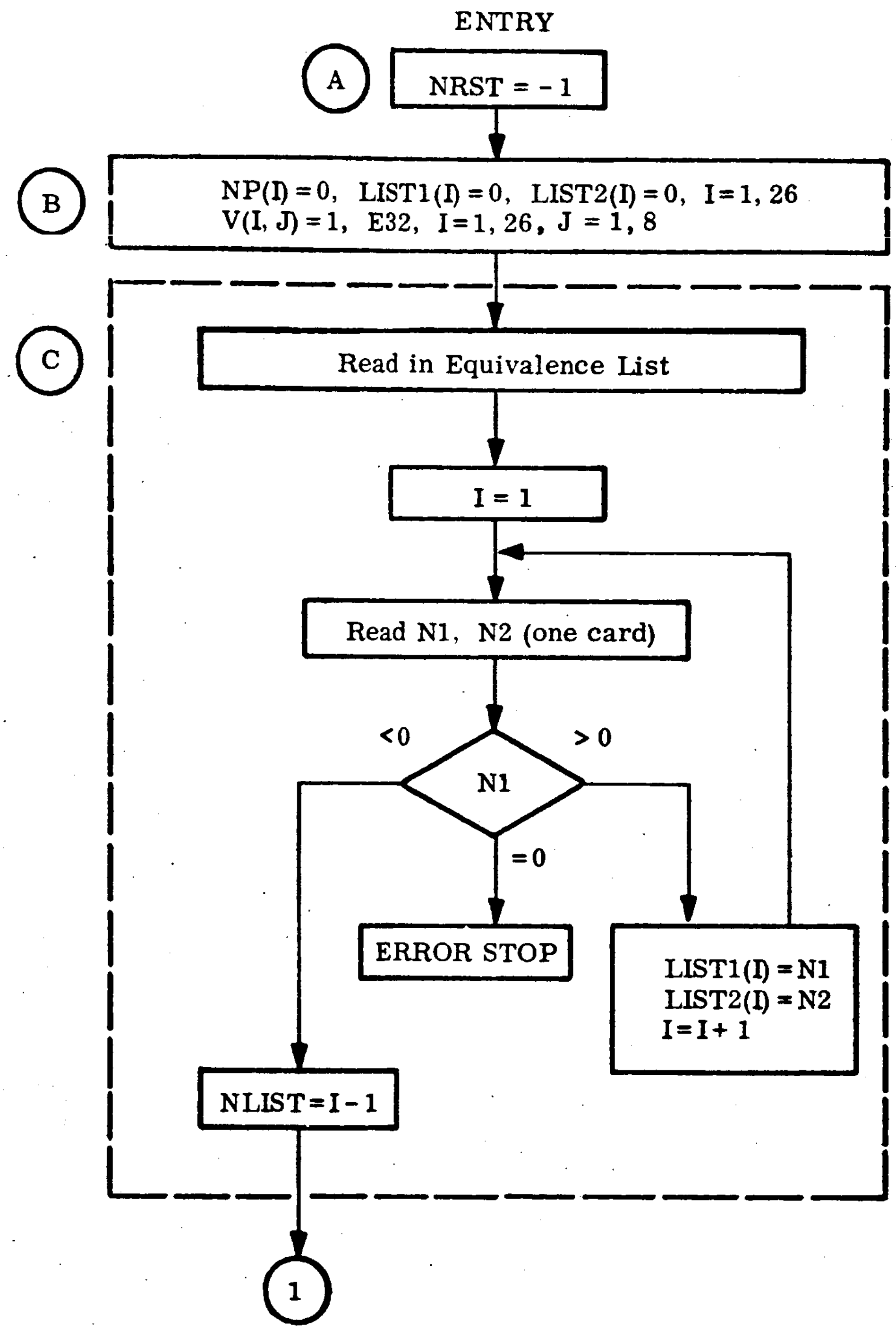
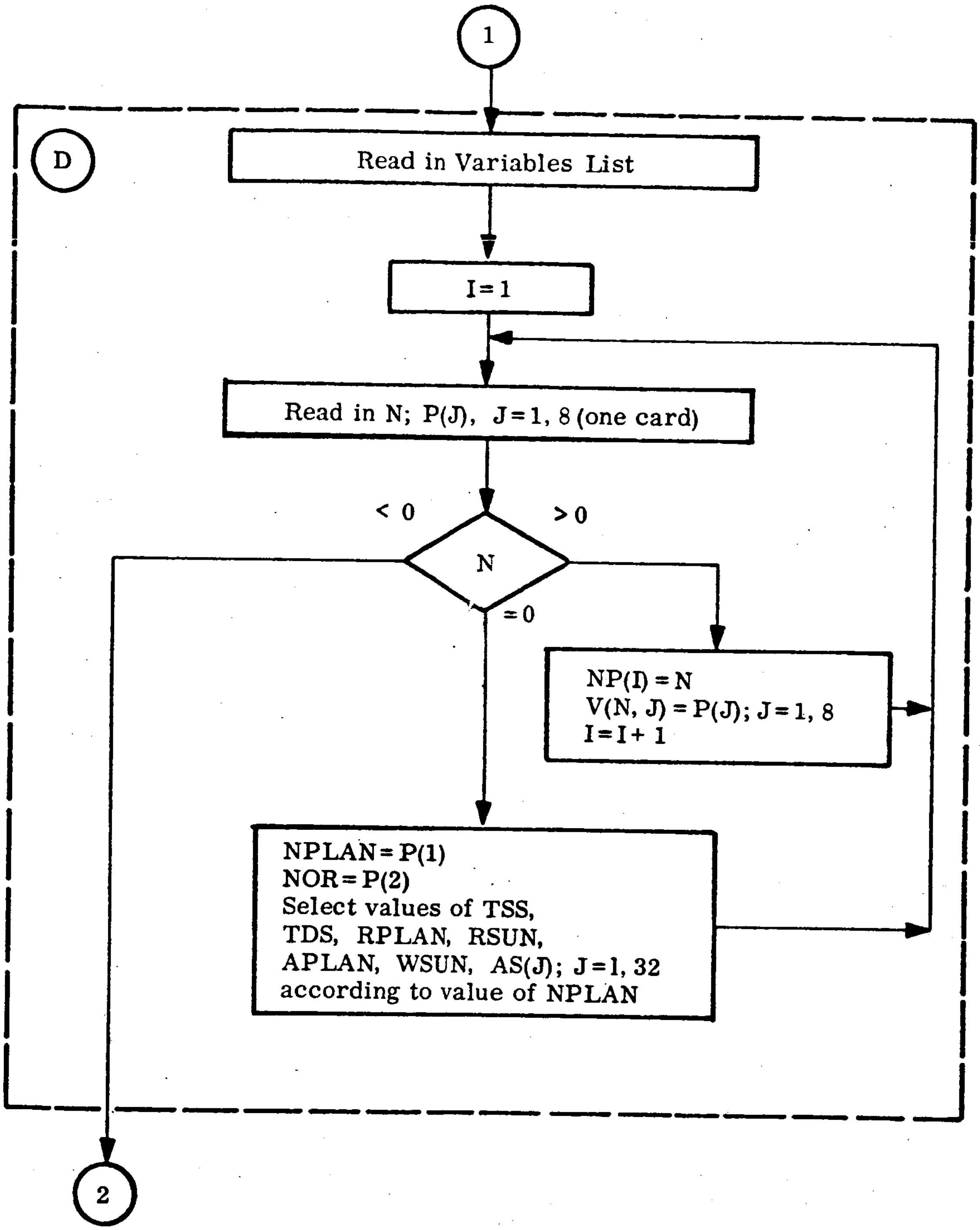


Fig. 4-4 MAINP Flow Chart



1
D
Read in Variables List
I = 1
Read in N; P(J), J = 1, 8 (one card)
< 0
> 0
N
= 0
NP(I) = N
V(N, J) = P(J); J = 1, 8
I = I + 1
NPLAN = P(1)
NOR = P(2)
Select values of TSS,
TDS, RPLAN, RSUN,
APLAN, WSUN, AS(J); J = 1, 32
according to value of NPLAN
2

Fig. 4-4 (Cont.)

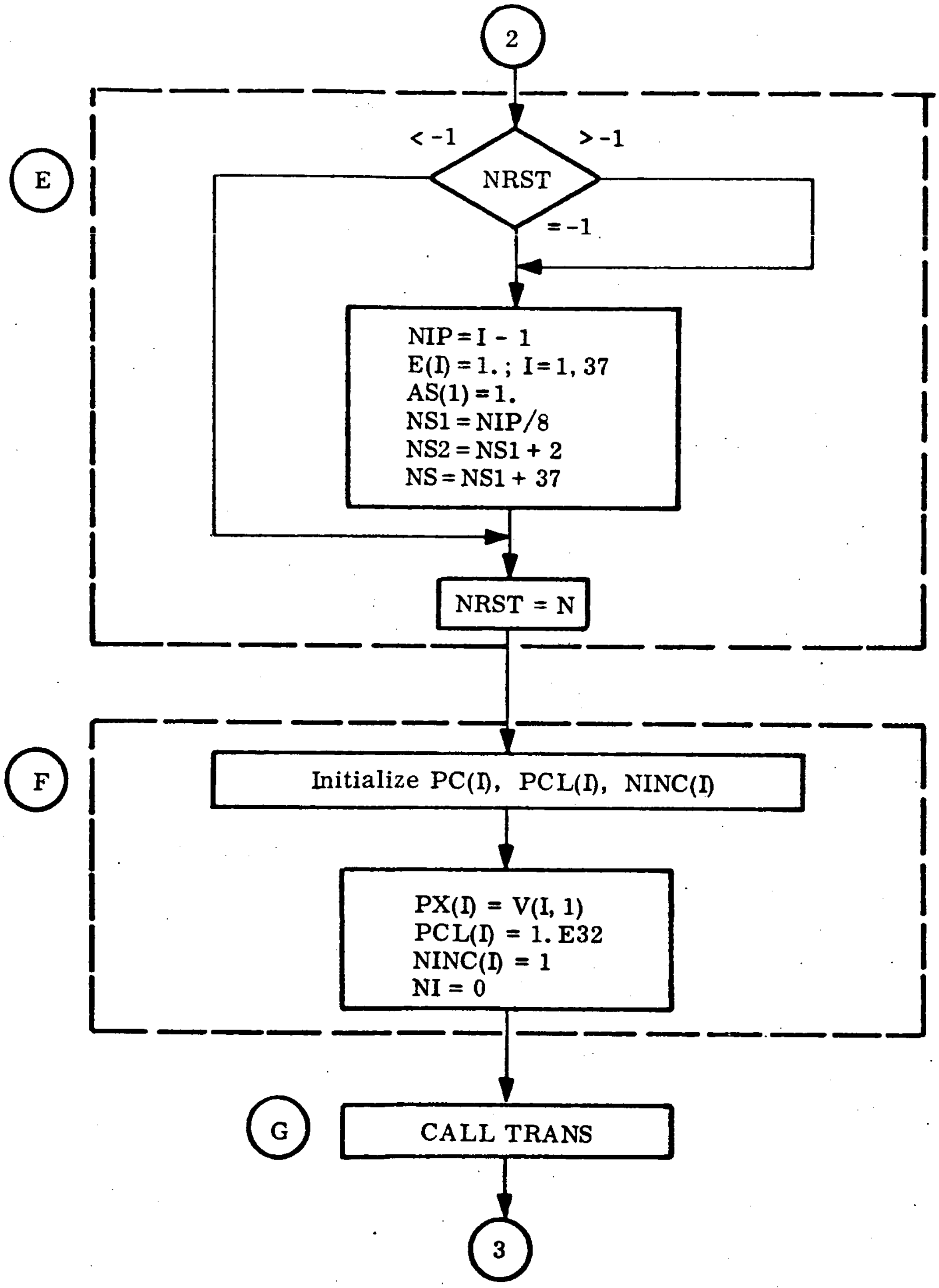

2
E
< -1
> -1
NRST
= -1
NIP = I - 1
E(I) = 1. ; I = 1, 37
AS(1) = 1.
NS1 = NIP/8
NS2 = NS1 + 2
NS = NS1 + 37
NRST = N
F
Initialize PC(I), PCL(I), NINC(I)
PX(I) = V(I, 1)
PCL(I) = 1. E32
NINC(I) = 1
NI = 0
G
CALL TRANS
3

Fig. 4-4 (Cont.)

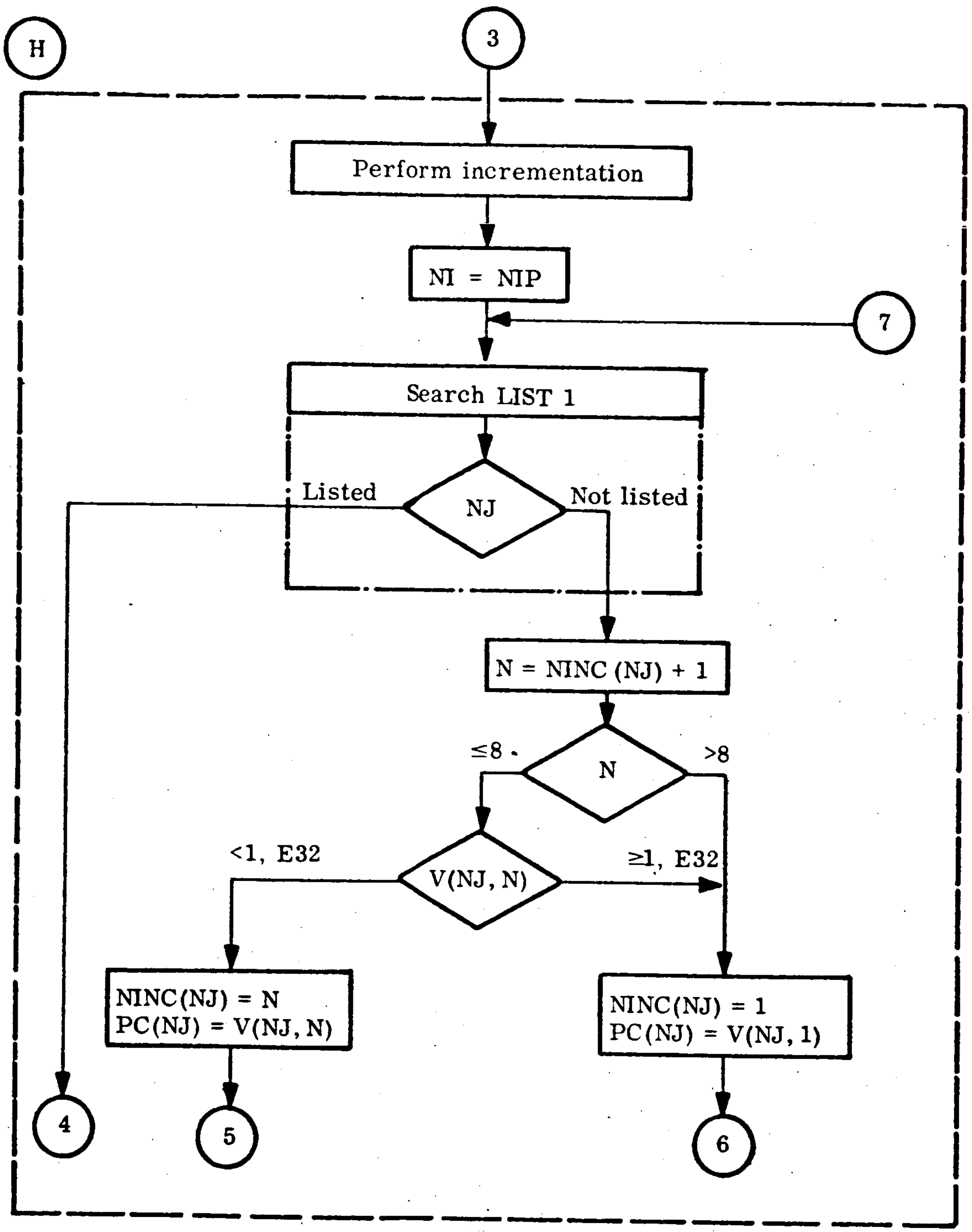

H
3
Perform incrementation
NI = NIP
7
Search LIST 1
Listed
NJ
Not listed
N = NINC (NJ) + 1
≤8
N
>8
<1, E32
V(NJ, N)
≥1, E32
NINC(NJ) = N
PC(NJ) = V(NJ, N)
NINC(NJ) = 1
PC(NJ) = V(NJ, 1)
4
5
6

Fig. 4-4 (Cont.)

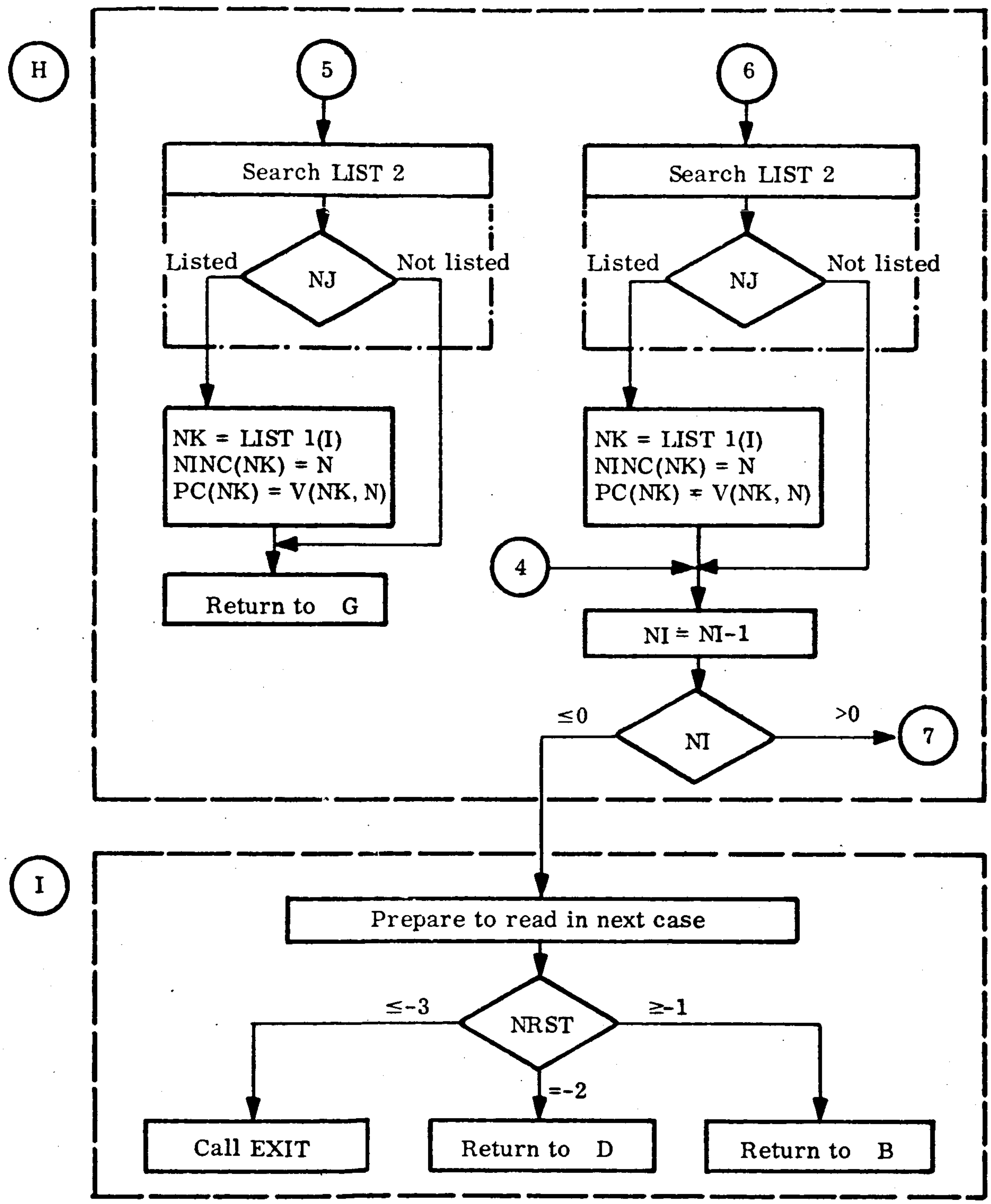


Fig. 4-4 (Concluded)

- NRST: Restart flag (-1 = new case follows, -2 = restart follows, -3 = nothing follows)
- V(I, J): Parameter values (I = parameter ID; J = Jth value, up to eight values per parameter; see Variables List in Input section
- LISTI(I), LIST2(I): List of parameters that are to be varied together (see Equivalence List in Input section

Output. The following quantities are computed in MAINP before a transfer to TRANS:

- APLAN: Planet area = 4π*(RPLAN)^2
- AS(I), I = 1 to 37: α_s of sun and planet ($\alpha_{s(1)}$ = 1., $\alpha_{s(2-37)}$ = 1-ρ planet)
- E(I), I = 1 to 37: G of sun and planet ($G_{(1-37)}$ = 1.)
- NI: ID of next parameter to be incremented (NI = 0 for first run of a case, using initial values of all parameters; NI > 0 for all subsequent runs)
- NS: Total number of nodes (1 sun + 36 planet + 2 or 3 satellite)
- NS1: Number of satellite surfaces (2 for configuration 1a, 3 for configuration 1b)
- NS2: Number of surfaces (1 sun + 1 planet + 2 or 3 satellite)
- PC(I): List of the current values of the parameters
- PCL(I): List of the values of the parameters used in the preceding run (in the first run, NI = 0, PCL(I) = 1.E32 for all I)
- RPLAN: Planet radius
- RSUN: Distance from planet to sun
- TDS: Planets dark-side surface temperature
- TSS: Planets subsolar surface temperature
- WSUN: Emissive power of sun = σT_{sun}^4

Method. MAINP is primarily a "bookkeeping" routine to keep track of where in the parametric study the program is. MAINP can be divided into nine main sections (letters A through I on the flow chart, Fig. 4-4).

At entry (section A), set NRST = -1 to indicate that the first case read in is a "new case," and initialize the NP, LIST1, LIST2, and V arrays (section B).

Read in the Equivalence List one card at a time, storing the ID's in LIST1 and LIST2, and maintaining a count of the cards read in (section C). The end of the list is signalled by a card containing a -1. When this card is encountered, set NLIST equal to the number of cards read in (not counting the -1 card) and start reading the Variables List (section D). Each card of the Variables List contains the parameter ID, which is stored in NP in the order read in, and also contains the up to eight values that the parameter will have, which are stored in the V array in order of the parameter ID's. For example, the values of G, (parameter number 10) are stored in V(10, J); J = 1, 8. (Note that new ID numbers are assigned to parameters 101 through 208 so as to form continuous lists. The new ID's are equal to ID + 2-92*(ID/100), where (ID/100) is the integral part of the quotient.) When (or if) a card containing an ID of 0 is encountered, the program recognizes it as the planet-orientation card. Instead of placing the data on the card in the NP and V arrays, the program sets the orientation flag (NOR) and selects the appropriate set of planet parameters from an internally stored list. The end of the Variables List is signalled by a card containing a negative number in the ID column. In addition to signalling the end of the list, this negative number indicates the type of case that follows the current case. A -1 indicates that a "new case" follows; -2 indicates that a "restart" follows; -3 indicates nothing follows, i.e. – this is the last case of the job.

After the Variables List is read in, the value of NRST is tested (section E). At this point, NRST indicates the type of the current case (new case or restart). If it is a new case, new values are obtained for NIP, E(I), I = 1, 37, AS(1), NS1, NS2, and NS. If it is a restart, these quantities remain unchanged. In either event, NRST is changed to indicate the type of case that is to follow.

The program now proceeds to the computation and incrementing phase. The first step of this phase is initialization of the PC, PCL, and NINC arrays and NI (section F). The first value of each parameter is placed in the PC array, the PCL array is set equal to 1. E32 – an arbitrary number used only to make PC(I) and PCL(I) unequal – and the NINC array is set equal to 1 to indicate that the first value of each parameter is obtained in PC. NI is set equal to 0 to indicate that this is the start of the first run of the case.

The next step is to CALL TRANS (section G) to compute the fluxes based on the values of the parameters contained in the PC array. After returning from TRANS, the parameters are incremented (section H). The last parameter read in is incremented through each of its values, incrementing by 1 the value in NINC that corresponds to the last parameter, and returning to section G (CALL TRANS) after each increment. When this incrementation is complete [NINC(ID) = 8 or V(ID, J) = 1.E32], reset the last parameter to its initial value, set the corresponding value in NINC to 1, increment the next-to-last parameter read in, and return to section G. Continue in this manner, incrementing the last parameter read in most frequently, the next-to-last next most frequently and so on, until each of the parameters has been incremented through each of its values. Any parameter whose ID is contained in the LIST1 array is incremented along with its counterpart in the LIST2 array but is not incremented in the normal sequence.

On completion of the case, test the value of NRST to see what data must be read in for the next case. If NRST = -1 ("new case"), return to section B to read in the new Equivalence List. If NRST = -2 ("restart"), return to section D to read in the modification to the Variables List. If NRST = -3, unload the output tape for printing and call EXIT.

4.2.3 TRANS Subroutine (See Flow Chart, Fig. 4-5)

Purpose. TRANS interprets the data output from MAINP for use in the remainder of the program, and transfers to the appropriate subroutine for further computation.

Input. Input is the same as the output from MAINP. In particular, the quantities PC(I), PCL(I), NI, NOR, RPLAN, and RSUN are used in the TRANS subroutine.

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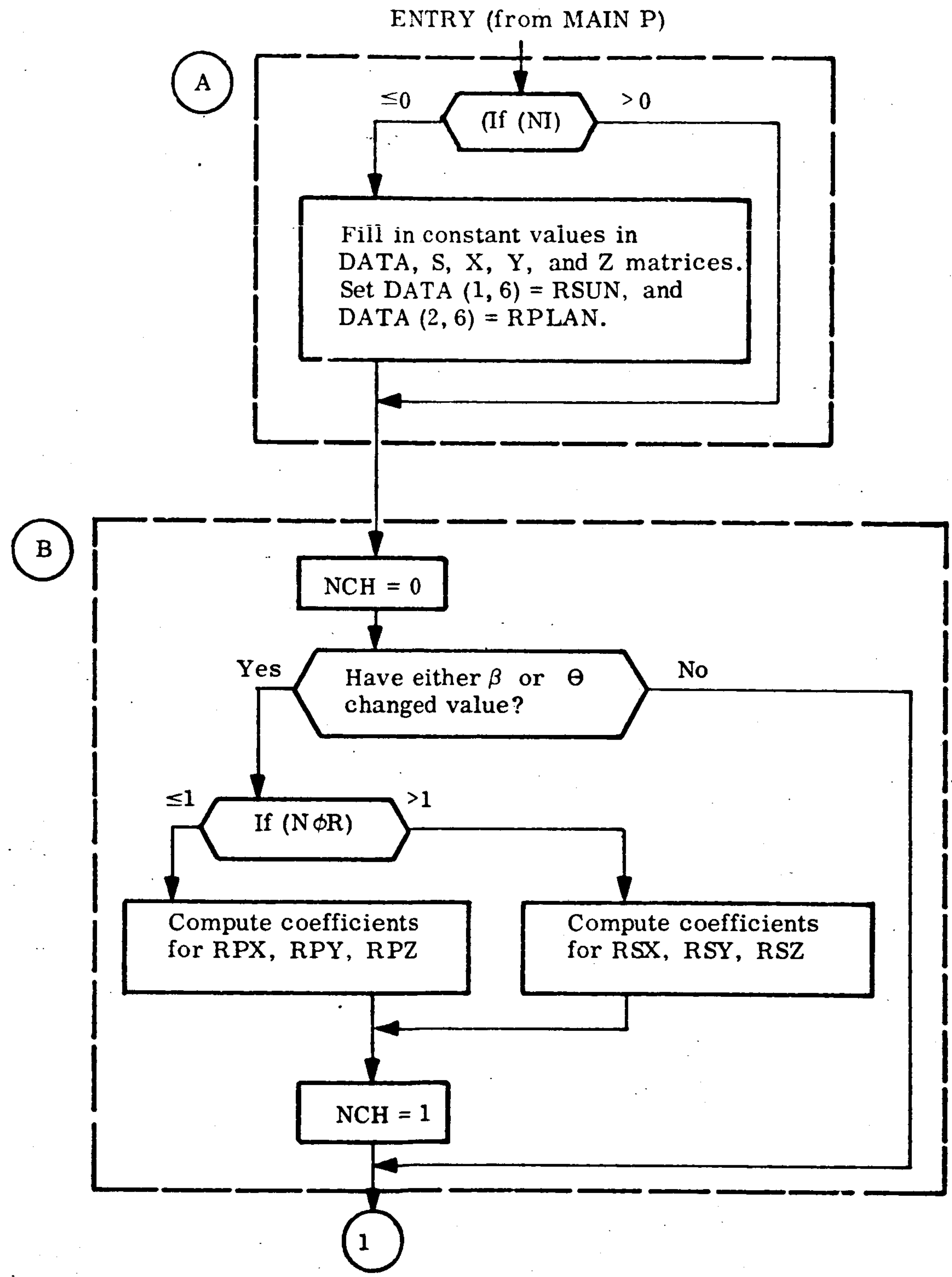

Fig. 4-5 TRANS Flow Chart

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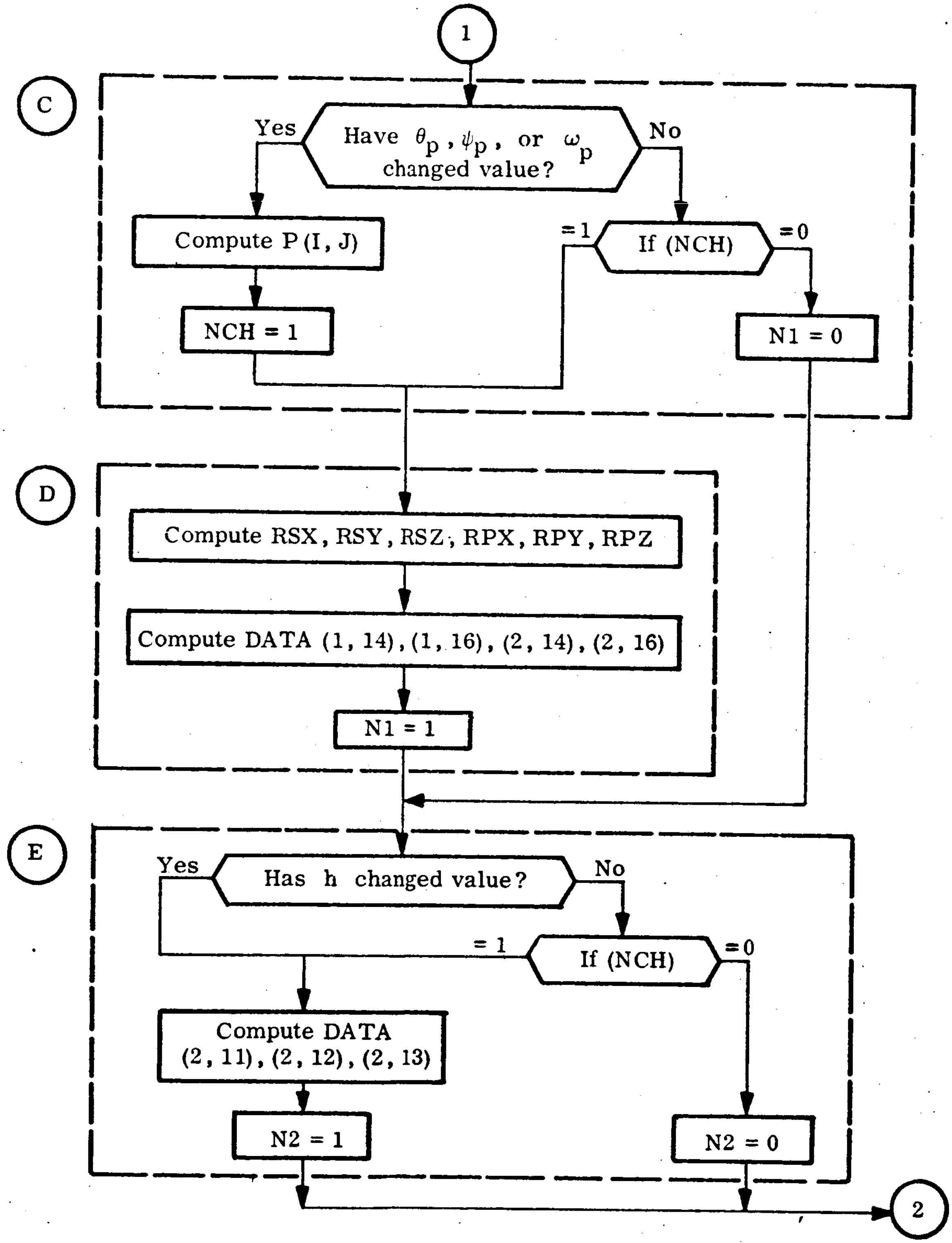

Fig. 4-5 (Cont.)

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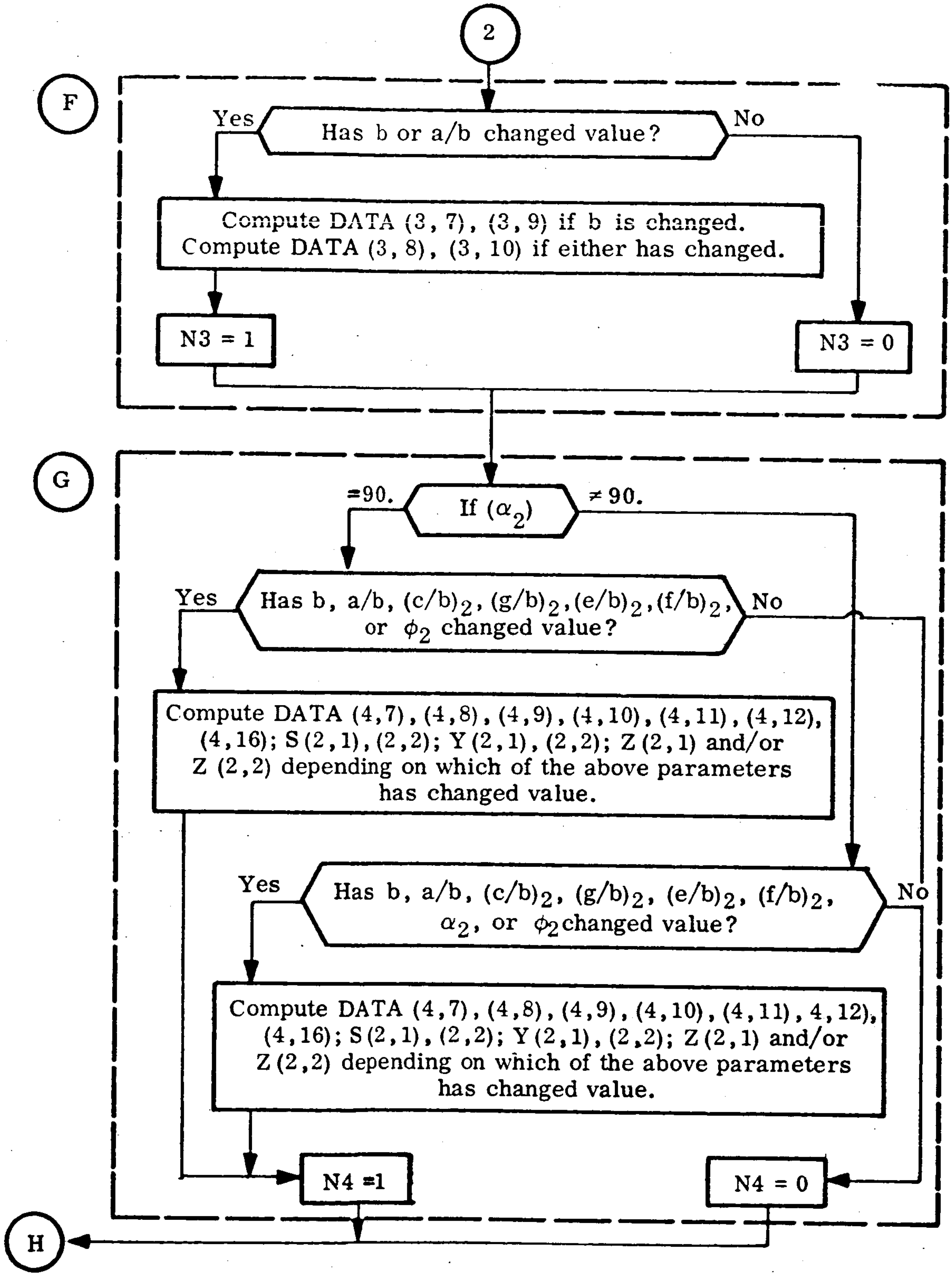
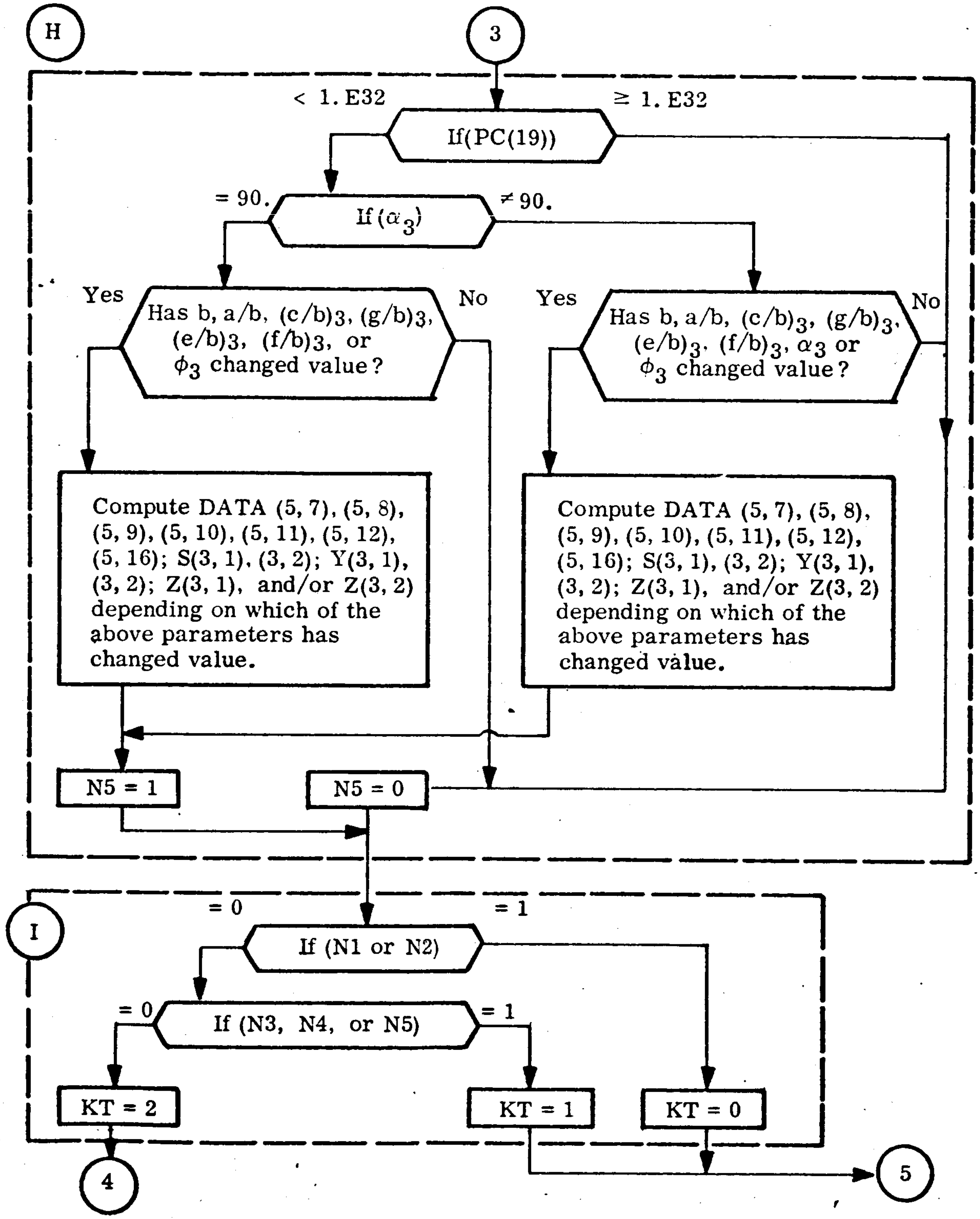


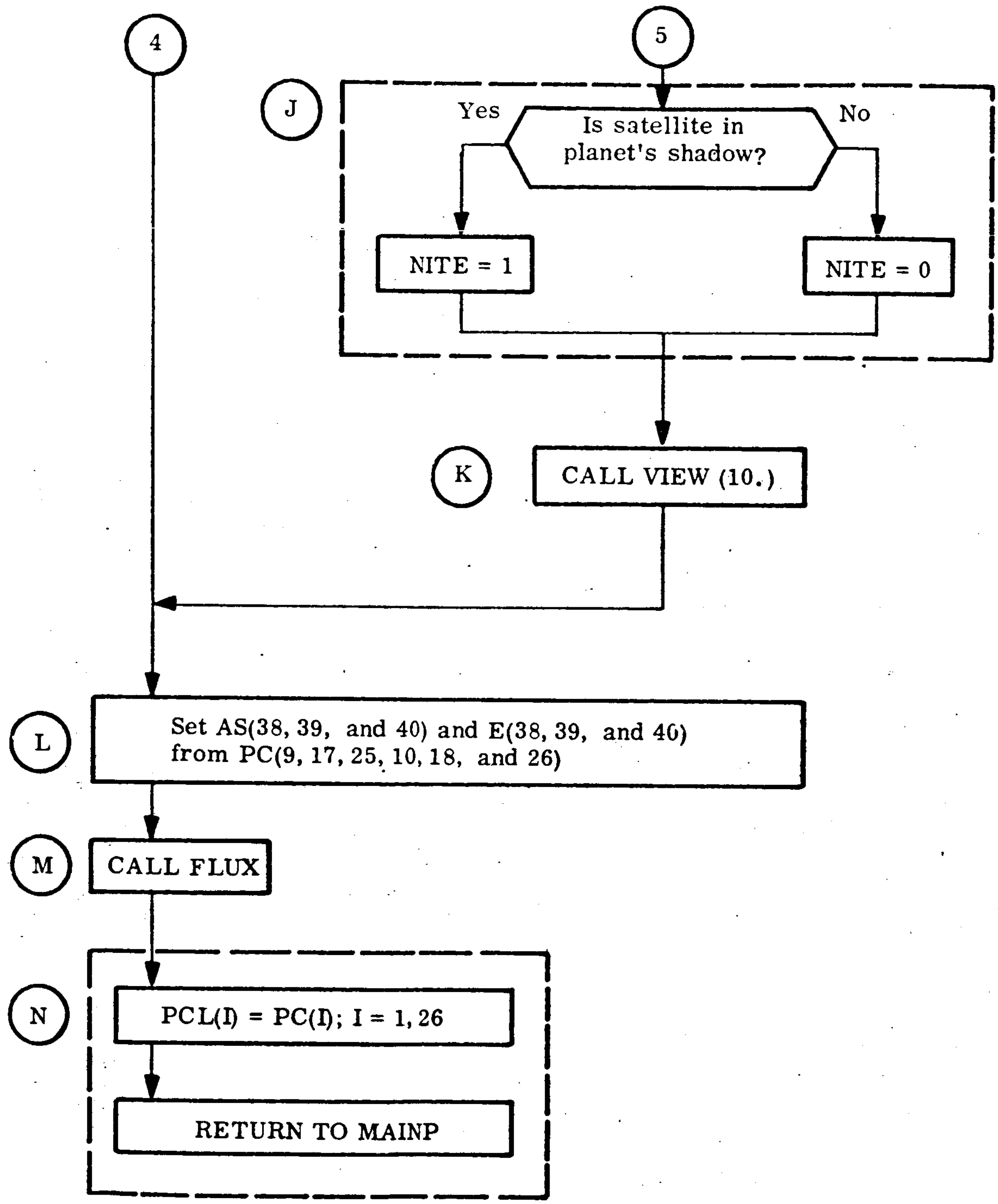
2
F
Yes
Has b or a/b changed value?
No
Compute DATA (3, 7), (3, 9) if b is changed.
Compute DATA (3, 8), (3, 10) if either has changed.
N3 = 1
N3 = 0
G
=90.
If (α2)
≠90.
Yes
Has b, a/b, (c/b)2, (g/b)2, (e/b)2, (f/b)2, or φ2 changed value?
No
Compute DATA (4,7), (4,8), (4,9), (4,10), (4,11), (4,12), (4,16); S (2,1), (2,2); Y (2,1), (2,2); Z (2,1) and/or Z (2,2) depending on which of the above parameters has changed value.
Yes
Has b, a/b, (c/b)2, (g/b)2, (e/b)2, (f/b)2, α2, or φ2 changed value?
No
Compute DATA (4,7), (4,8), (4,9), (4,10), (4,11), 4,12), (4,16); S (2,1), (2,2); Y (2,1), (2,2); Z (2,1) and/or Z (2,2) depending on which of the above parameters has changed value.
N4 =1
N4 = 0
H

Fig. 4-5 (Cont.)



Numerals within parentheses represent subscripts

Fig. 4-5 (Cont.)



Numerals within parentheses represent subscripts

Figure 4-5 (Concluded)

Output. There are three transfer points from TRANS: to VIEW subroutine, to FLUX subroutine, and return to MAINP. The following quantities are computed in TRANS prior to the transfer to VIEW:

- DATA(I, J), LDATA(I, J): These two together constitute the DATA matrix. They occupy the same region in core through use of the statement EQUIVALENCE (DATA, LDATA). In this way, floating-point numbers can be stored in the DATA matrix through use of DATA(I, J), and fixed-point numbers can be stored by use of LDATA(I, J). Thus, the DATA matrix contains a mixture of floating-point and fixed-point numbers. The DATA matrix performs the same function here that it does in the generalized program; i. e. it contains the description of each of the surfaces involved in the flux computation. The content of the DATA matrix is shown in Fig. 4-6. The expressions in Fig. 4-6 refer to the dimensions shown in Fig. 4-1. The sun [DATA(I, J)] is assumed to be a rectangle with an area equal to the area of the solar disk. Each of the satellite surfaces [DATA(3, J), DATA(4, J), and DATA(5, J)] is divided into 16 incremental surfaces.
- S(I, J): The S matrix, used in the SHADE subroutine, contains the location of the intersection of each satellite surface with its z' axis (see Figs. B7, B8, and B9 in Appendix B).
- X(I, J): The X matrix, used in the SHADE subroutine, contains the X, Y, and Z components of each satellite surface's X' axis
- Y(I, J): The Y matrix, used in the SHADE subroutine, contains the X, Y, and Z components of each satellite surface's Y' axis.
- Z(I, J): The Z matrix, used in the SHADE subroutine, contains the X, Y, and Z components of each satellite surface's Z' axis.
- NITE: This is a flag, used in the OMEGA subroutine to indicate whether the satellite is in direct sunlight (NITE = 0) or in the planet's shadow (NITE = 1).
- NI: This is a flag, used in the OMEGA subroutine to indicate whether the location of the satellite relative to the sun has been changed between this run and the preceding run.
- N2: This is a flag, used in the OMEGA subroutine to indicate whether the location of the satellite relative to the planet has been changed.

- N3, N4, N5: These are flags, used in the OMEGA subroutine to indicate whether the dimensions or orientation of the satellite surface has been changed.
- KT: This is a flag to show what must be computed in VIEW.

After returning from VIEW and before transferring to FLUX, the following quantities are obtained from PC(I):

- AS(I), I = 38, NS: α_s of the satellite surfaces
- E(I), I = 38, NS: ϵ of the satellite surfaces

After returning from FLUX and before returning to MAINP, the PCL(I) list is made equal to the PC(I) list. The current run now becomes the preceding run.

Method. TRANS subroutine can be divided into 14 main sections (letters A through N on the flow chart, Fig. 4-4).

Large portions of the DATA matrix remain constant throughout each case (see Fig. 4-6). So, on entry from MAINP (section A), test NI to see whether this is the first run of a case. If it is, fill in these constant values.

In sections B through H, each of the parameters is tested to see if it has been changed since the previous run by comparing the value listed in the PC array (current value) with the value listed in the PCL array (previous value). If the parameter has changed, each element of the DATA matrix that is affected by the parameter is changed to reflect the new value. In addition, a flag is set for each surface (sun, planet, surface 1, surface 2, and, if it exists, surface 3) to indicate whether any of the elements of the DATA matrix that apply to that surface have been changed. These flags – N1, N2, N3, N4, and N5 – are used in the other subroutines to eliminate unnecessary calculations.

After completing the DATA, S, X, Y, and Z matrices, the flags N1 through N5 are tested and two more flags, KT and NITE, are set (sections I and J). These flags are

DAT

I	Surface	J Quantity	1 ILK	2 $N\beta$	3 $N\gamma$	4 $NV\beta$	5 $NV\gamma$	6 α	7 β min.	8 γ min.	9 β max.	10 γ max.	
1	Sun		-1	1	1	1	1	RSUN	-0.20196E10	-0.20196E10	0.20196E10	0.20196E10	
2	Planet		6	1	1	3	12	RPLAN	0	0	0	360.	-
3	Surface 1	(Primary)	1	4	4	1	1	0	-b/2	-a/2	b/2	a/2	
4	Surface 2	$\alpha_2 = 90.$ $\alpha_2 > 90.$ $\alpha_2 < 90.$	-1 3	4	4	1	1	0	$-c_2/2$ $f_2 - \frac{a}{2} + g_2 \tan \alpha_2$	$-\frac{a}{2}+g_2$ $90-\alpha_2$ $90+\alpha_2$	$c_2/2$ $c_2+\beta$ min.	$\frac{a}{2}+g_2$ α_2-90 $270-\alpha_2$	(
5	Surface 3	$\alpha_2 = 90.$ $\alpha_2 > 90.$ $\alpha_2 < 90.$	1 -3	4	4	1	1	0	$-c_3/2$ $f_3 - \frac{a}{2} + g_3 \tan \alpha_3$	$-\frac{a}{2}+g_2$ $90-\alpha_3$ $90+\alpha_3$	$c_3/2$ $c_3+\beta$ min.	$\frac{a}{2}+g_2$ α_3-90 $270-\alpha_3$	(

A Matrix

11 R1	12 R2	13 R3	14 φ	15 ψ	16 ω
0	0	0	RSX<0: $-\arccos\left[RSY/\sqrt{(RSX)^2+(RSY)^2}\right]$ RSX>0: $\arccos\left[RSY/\sqrt{(RSX)^2+(RSY)^2}\right]$ RSX = 0 RSY < 0: 180. RSY > 0: 0.	0	-acrs (RSZ)
H * RPZ	-H * RPY	-H * RPZ	RPX<0: $-\arccos\left[RPT/\sqrt{(RPX)^2+(RPY)^2}\right]$ RPX>0: $\arccos\left[RPT/\sqrt{(RPX)^2+(RPY)^2}\right]$ RPX = 0 RPY<0: 180. RPY>0: 0.	0	-acrs (RPZ)
0	0	0	0	0	0
$_2 - \beta$ min.) $\sin\varphi_2$	$(e_2+\frac{b}{2})-(f_2-\beta$ min.) $\cos\varphi_2$	0	0	0	$-\varphi_2$ $180 - \varphi_2$
$_3 - \beta$ min.) $\sin\varphi_3$	$(e_3+\frac{b}{2})-(f_3-\beta$ min.) $\cos\varphi_3$	0	0	0	$180 + \varphi_3$ φ_3

Fig. 4-6 DATA Matrix

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S Matrix

J =	1	2	3
I = 1	0.	0.	0.
2	DATA (4, 11)	DATA (4, 11)	0.
3	DATA (5, 11)	DATA (5, 11)	0.

X Matrix

J =	1	2	3
I = 1	0.	0.	1.
2	0.	0.	1.
3	0.	0.	1.

Y Matrix ($\alpha_2 = 90$)

J =	1	2	3
I = 1	0.	1.	0.
2	$-\sin \varphi_2$	$\cos \varphi_2$	0.
3	$-\sin \varphi_3$	$-\cos \varphi_3$	0.

Y Matrix ($\alpha_2 \neq 90$)

J =	1	2	3
I = 1	0.	1.	0.
2	$\sin \varphi_2$	$-\cos \varphi_2$	0.
3	$\sin \varphi_3$	$\cos \varphi_3$	0.

Z Matrix ($\alpha_3 = 90$)

J =	1	2	3
I = 1	1.	0.	0.
2	$\cos \varphi_2$	$\sin \varphi_2$	0.
3	$-\cos \varphi_3$	$\sin \varphi_3$	0.

Z Matrix ($\alpha_3 \neq 90$)

J =	1	2	3
I = 1	1.	0.	0.
2	$-\cos \varphi_2$	$-\sin \varphi_2$	0.
3	$\cos \varphi_3$	$-\sin \varphi_3$	0.

RSX = P(3, 1)

RST = P(3, 2)

RSZ = P(3, 3)

RPX = P(1, 1) s

RPY = P(1, 2) s

RPZ = P(1, 3) s

$P(1, 1) = \cos \psi_p$ c

$P(2, 1) = \cos \psi_p$ s

$P(3, 1) = \sin \psi_p$

Sun-Oriented (NOR = 1)	Planet-Oriented (NOR = 2)
	$-P(1,1)\sin\theta\cos\beta + P(2,1)\sin\beta + P(3,1)\cos\theta\cos\beta$
	$-P(1,2)\sin\theta\cos\beta + P(2,2)\sin\beta + P(3.2)\cos\theta\cos\beta$
	$-P(1,3)\sin\theta\cos\beta + P(2,3)\sin\beta + P(3,3)\cos\theta\cos\beta$
in $\theta - P(2,1)\cos\theta\sin\beta + P(3,1)\cos\theta\cos\beta$	$P(3,1)$
in $\theta - P(2,2)\cos\theta\sin\beta + P(3,2)\cos\theta\cos\beta$	$P(3,2)$
in $\theta - P(2,3)\cos\theta\sin\beta + P(3,3)\cos\theta\cos\beta$	$P(3,3)$

os φ_p $\quad P(1,2) = \cos\omega_p \sin\varphi_p - \sin\omega_p \sin\psi_p \cos\varphi_p$ $\quad P(1,3) = -\cos\omega_p \sin\psi_p \cos\varphi_p - \sin\omega_p \sin\varphi_p$

in φ_p $\quad P(2,2) = \cos\omega_p \cos\varphi_p + \sin\omega_p \sin\psi_p \sin\varphi_p$ $\quad P(2,3) = \cos\omega_p \sin\psi_p \sin\varphi_p - \sin\omega_p \cos\varphi_p$

$P(3,2) = \sin\omega_p \cos\psi_p$ $\quad P(3,3) = \cos\omega_p \cos\psi_p$

Fig. 4-6 (Concluded)

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also used to eliminate unnecessary calculations in the other subroutines. If KT < 2, one or more of the surfaces has been changed, and it is necessary to recalculate the view factors pertaining to the changed surfaces. In this case, transfer to VIEW through the CALL VIEW (ERR) statement (section K), with ERR = 10. ERR is the percent of error allowable in computing the view factor between the satellite surfaces and the planet (see Appendix D). For the parametric study, an error of 10 percent or less has been selected. On returning from VIEW, proceed to section L.

If KT = 2, none of the surface dimensions or locations has changed, so it is not necessary to recalculate the view factors. The program skips directly to section L, where the remainder of the AS and E arrays are filled, and then transfers to FLUX through the CALL FLUX statement (section M) to compute the heat fluxes.

On return from FLUX, the PCL array is set equal to the PC array (section N); the current run now becomes the previous run. The program then returns to section H of MAINP, where the new parametric values are obtained for the next run.

4.2.4 VIEW and VECTOR Subroutines (See Flow Chart, Fig. 4-7)

Purpose. The VIEW and VECTOR subroutines are essentially the same as the corresponding routines of the generalized program (see Appendix A), although some changes were made to take advantage of the more restricted nature of the parametric study. As in the generalized program, the number of incremental areas or elements in each planet mode is formed from ERR and the satellite altitude and then the ARA and POS arrays are computed from the data in the DATA matrix. The ARA and POS arrays are then transmitted to the OMEGA subroutine for computation of the view factors.

Input. Input is the same as the output from TRANS and MAINP. In particular, ERR, NI, N1, N2, N3, N4, N5, NS2, RPLAN, and the DATA and PC arrays are used in VIEW and VECTOR.

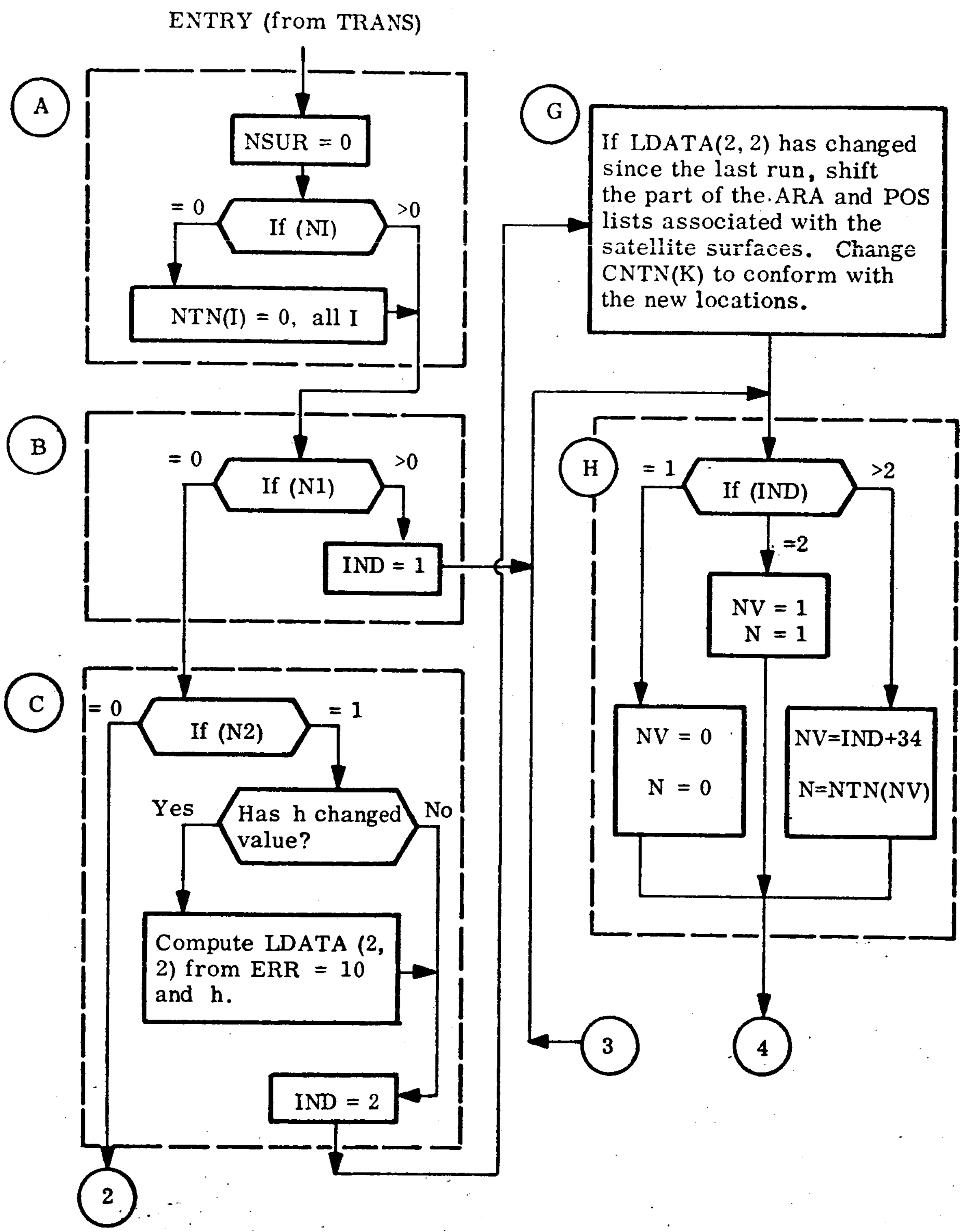

Fig. 4-7 VIEW Flow Chart

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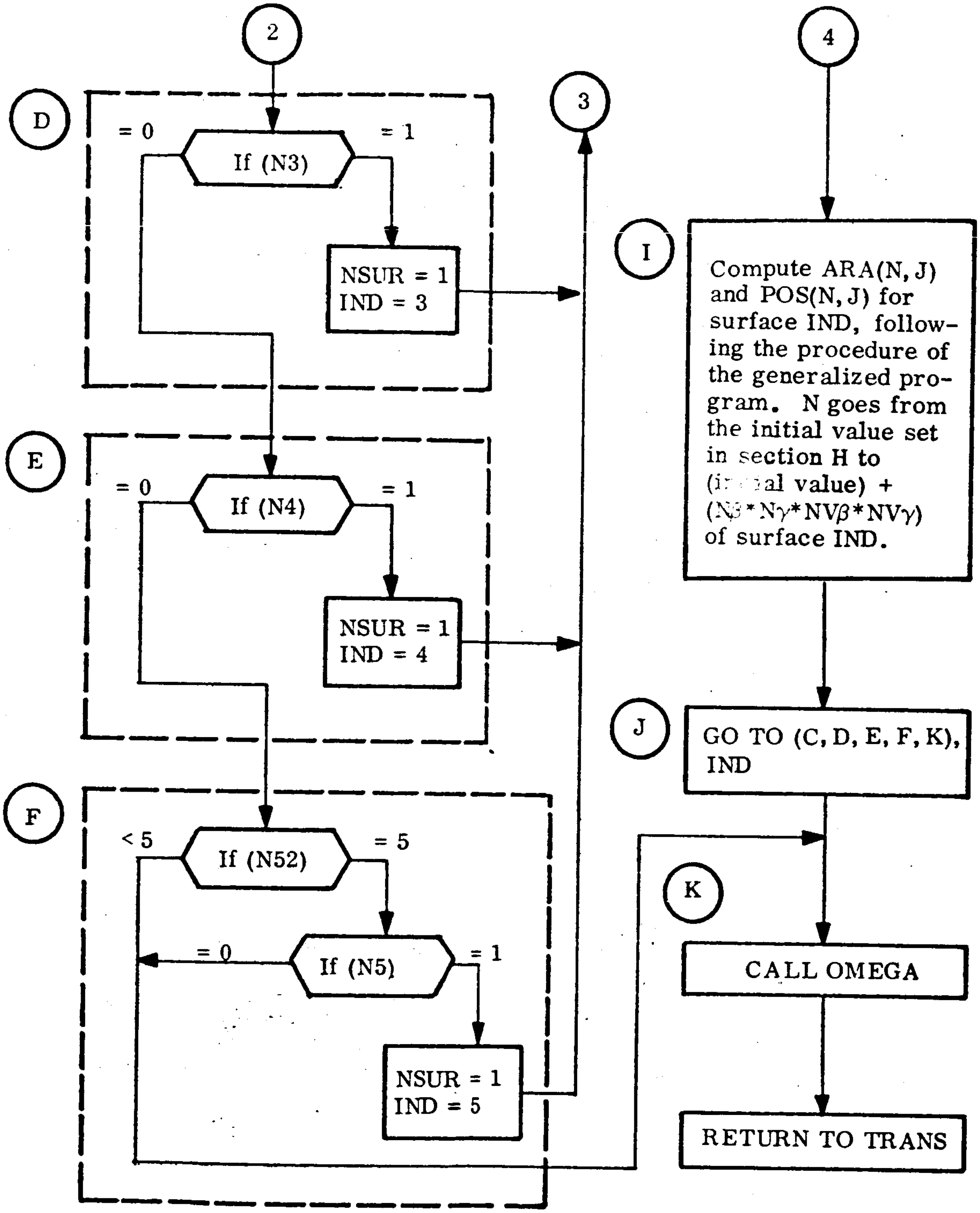

Fig. 4-7 (Concluded)

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Output. The following quantities are computed in the VIEW and VECTOR subroutines before a transfer to OMEGA:

- ARA(I, J): This consists of X(J = 3), Y(J = 2), and Z(J = 1) components of the area normal vector of the I^{th} incremental area or element.
- POS(I, J): This consists of X(J = 3), Y(J = 2), and Z(J = 1) components of the position vector of the center of the I^{th} incremental area or element.
- NTN(K): This is a list showing which portion of the ARA and POS arrays belongs to which node. NTN(K) contains the index I of the last incremental area in ARA(I, J) and POS(I, J) that belongs to node K.
- NSUR: This is a flag indicating whether the satellite surfaces have been changed between the preceding run and the current run. If N3 = N4 = N5 = 0, then NSUR = 0. If N3, N4, or N5 = 1, then NSUR = 1.

Method. The VIEW subroutine can be divided into eleven main sections (letters A through K on the flow chart, Fig. 4-7).

As stated above, these subroutines are essentially the same as the subroutines of the generalized program. The main difference is in subroutine VIEW. The generalized program recomputes the entire ARA and POS arrays at each entry from TRANS. In this parametric study, the restricted number and geometry of the surfaces make it feasible to treat the surfaces one at a time. If the surface has been changed since the last run, the corresponding part of ARA and POS are recomputed. If it has not, the corresponding part of ARA and POS is left unchanged.

On entry from TRANS, NSUR is set to 0, NI is tested, and, if NI = 0, the NTN array is initialized (section A). The program then checks whether each of the surfaces has been changed by testing N1, N2, N3, N4, and N5 (sections B through F). If N1, N3, N4, or N5 = 1, the program sets a return flag (IND) and goes to section H to compute the new ARA and POS values (sections H and I, and VECTOR subroutine). If N2 = 1, the program determines whether the number of planetary incremental areas must be changed (section C) and goes to section G, where the ARA and POS arrays are rearranged, before going to section H. After computing the new ARA and POS values for a surface, the program returns to test the next surface.

After each surface is tested and the new ARA and POS values are computed, the program transfers to the OMEGA subroutine for computation of view factors. On return from OMEGA, the program returns to section L of TRANS.

The VECTOR subroutine is essentially the same as in the generalized program (see Appendix A) except that it contains routines for the rectangle, trapezoid (or triangle), and sphere only.

4.2.5 OMEGA and SHADE Subroutines (See Flow Chart, Fig. 4-8)

Purpose. The OMEGA subroutine computes the view factor between each pair of nodes, and the area of each node, from the data in the ARA and POS arrays. The basic equation and method are the same as in the generalized program, although the subroutine itself has been modified considerably.

Input. Input is the same as the output from the TRANS and VIEW subroutines and MAINP. In particular, NI, NS, and RSUN from MAINP; N1, N2, N3, N4, N5, and NITE from TRANS; and NSUR and the ARA and POS arrays from VIEW are used in the OMEGA subroutine.

Output. The following quantities are computed in OMEGA before a return to the VIEW subroutine.

- FA(I, J): This is the view factor (actually view factors times area) between nodes I and J.
- AREA(J): This is the area of node I.
- COST(I): This is the cosine of the angle between the effective normal vector of each planet node and the planet-sun line.

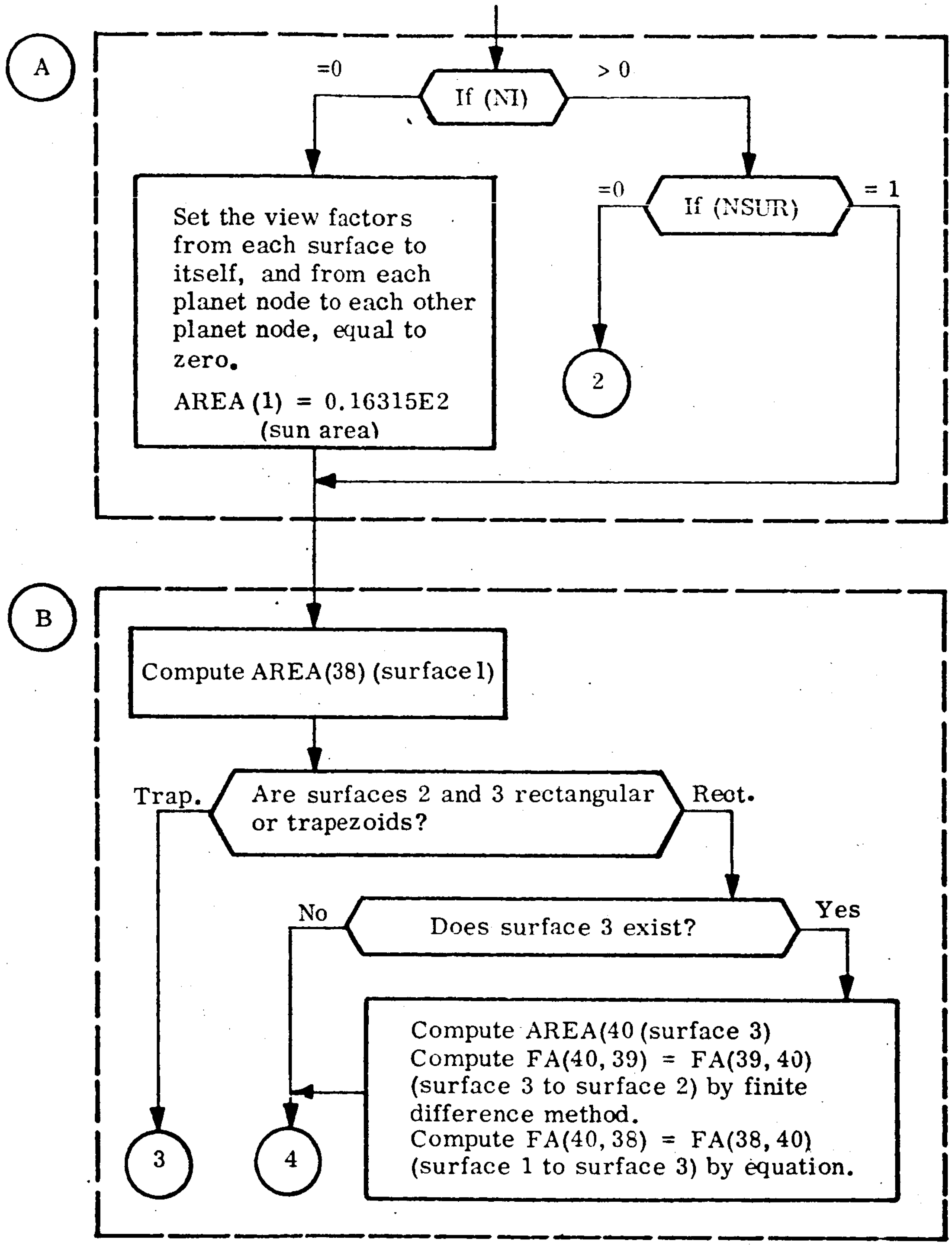

Fig. 4-8 OMEGA Flow Chart

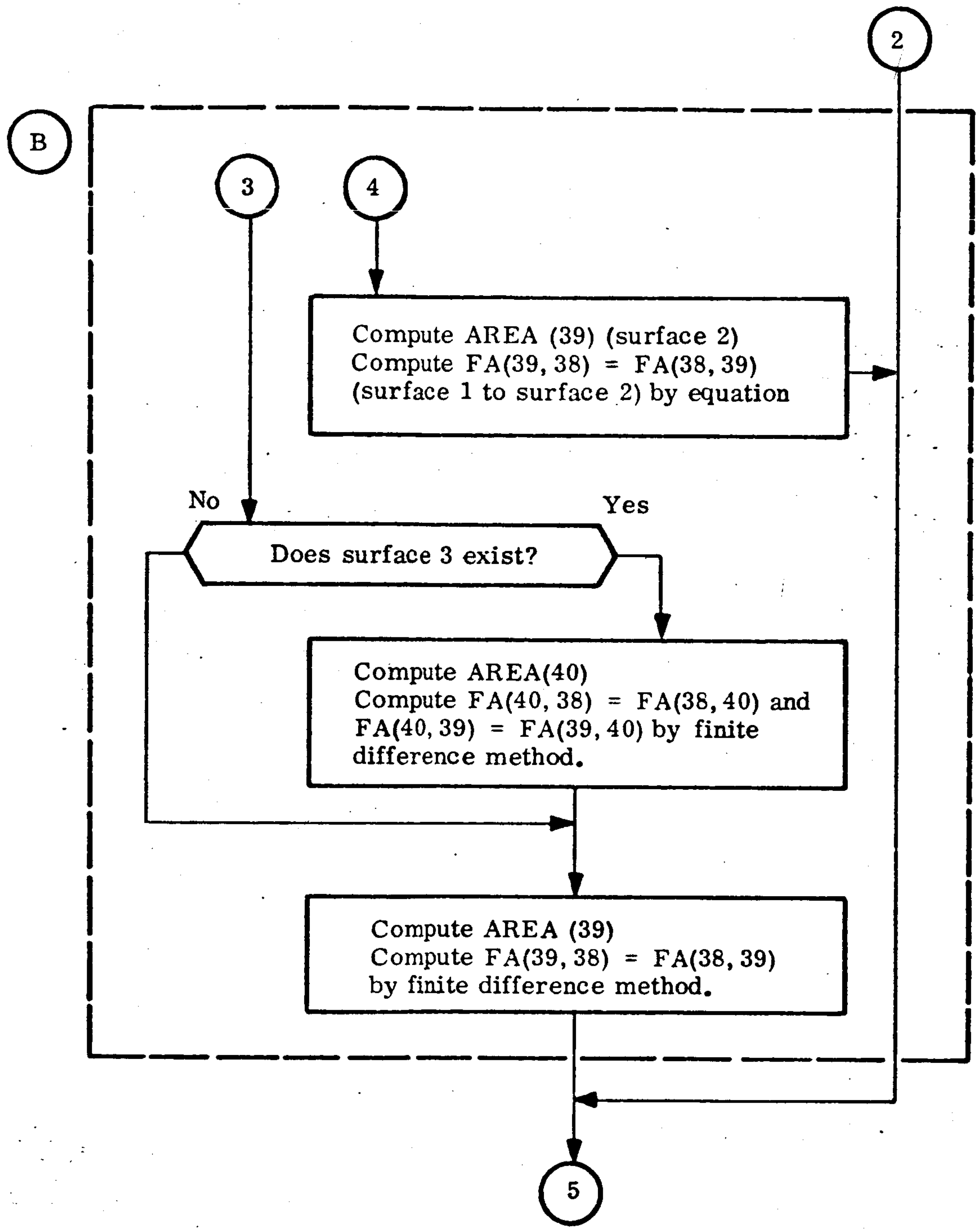
2
B
3
4
Compute AREA (39) (surface 2)
Compute FA(39, 38) = FA(38, 39)
(surface 1 to surface 2) by equation
No
Yes
Does surface 3 exist?
Compute AREA(40)
Compute FA(40, 38) = FA(38, 40) and
FA(40, 39) = FA(39, 40) by finite
difference method.
Compute AREA (39)
Compute FA(39, 38) = FA(38, 39)
by finite difference method.
5

Fig. 4-8 (Cont.)

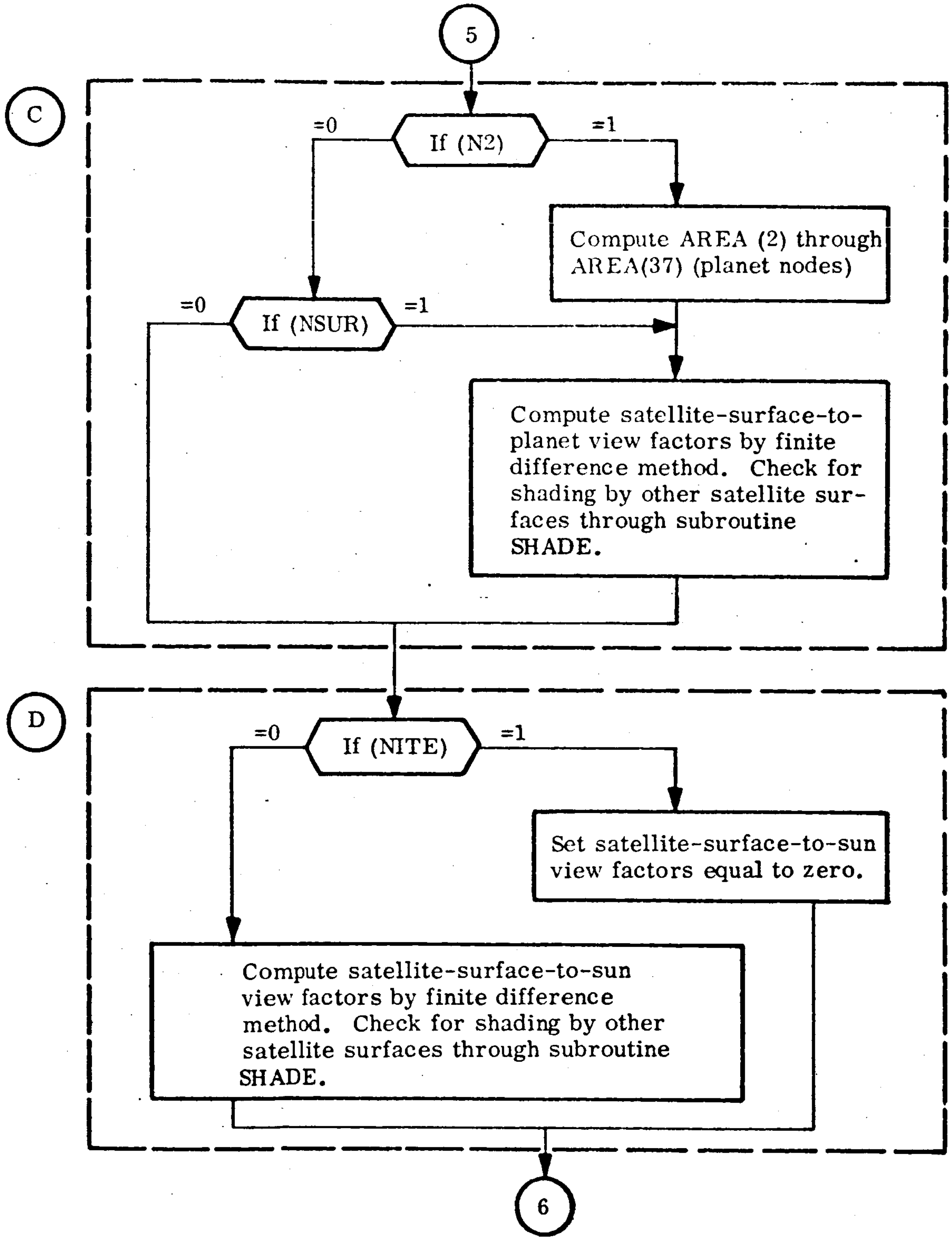
5
C
=0
If (N2)
=1
Compute AREA (2) through AREA(37) (planet nodes)
=0
If (NSUR)
=1
Compute satellite-surface-to-planet view factors by finite difference method. Check for shading by other satellite surfaces through subroutine SHADE.
D
=0
If (NITE)
=1
Set satellite-surface-to-sun view factors equal to zero.
Compute satellite-surface-to-sun view factors by finite difference method. Check for shading by other satellite surfaces through subroutine SHADE.
6

Fig. 4-8 (Cont.)

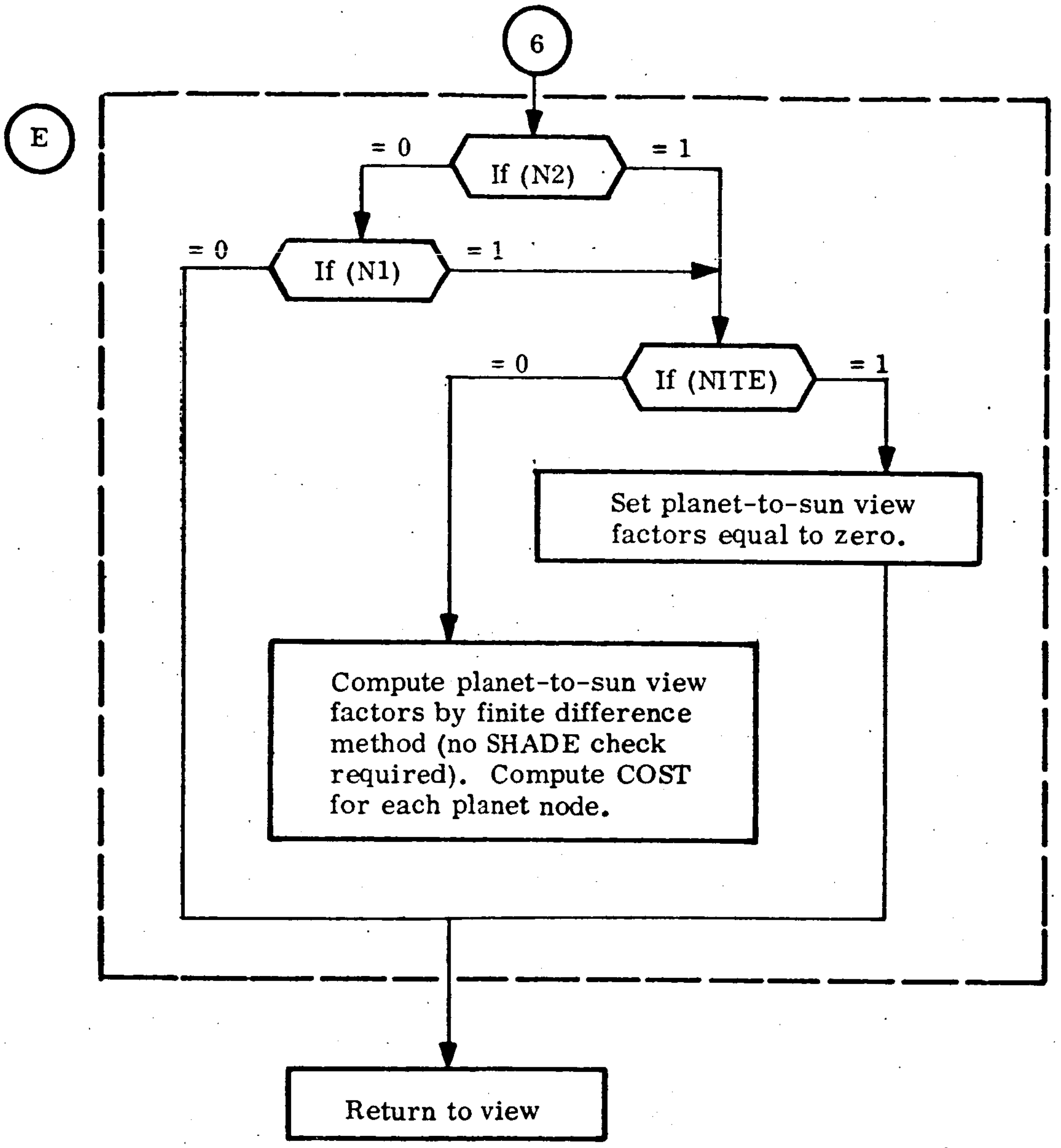

Fig. 4-8 (Concluded)

Method. The OMEGA subroutine can be divided into five main sections (letters A through E on the flow chart, Fig. 4-8).

The finite-difference method described in Appendix A is used to compute the view factors between the satellite surfaces and the sun, the satellite surfaces and the planet, and the planet and the sun. If surface 2 or 3 is a trapezoid, the finite difference technique is also used to compute the view factor between satellite surfaces 2 and 3 (if surface 3 exists) and between satellite surfaces 1 and 2, and 1 and 3 (again, if surface 3 exists). If surface 2 or 3 is a rectangle, the explicit equation of Ref. 4 for two rectangles with a common edge is used. In this way, the main source of inaccuracy in the finite difference technique was eliminated.

On entry from VIEW, NI is tested (section A). If NI = 0, the FA matrix is initialized by setting the view factor from each surface to itself equal to 0, and the program proceeds to section B. If NI > 0, NSUR is tested to see whether any of the satellite surfaces have been changed. If so (NSUR = 1), the program proceeds to section B. If not (NSUR = 0), the program skips to section C.

In section B, the satellite-surface-to-satellite-surface view factors and the satellite surface areas are computed and stored in FA and AREA respectively. View factors are computed by the finite difference method or, where applicable, by the explicit equation. It is not necessary to check for shading by other surfaces, because the geometry of the parametric study surfaces precludes shading.

In step C, N2 and NSUR are tested to see whether either the planet or one of the satellite surfaces has changed since the last run. If neither has the program proceeds to section D. If either has, the satellite surface-to-planet view factors are computed. It is necessary here to check each pair of incremental areas for shading by other satellite surfaces (see the SHADE subroutine).

The satellite-surface-to-sun view factors are computed in section D. If the satellite is in the planet's shadow (NITE = 1), each of these view factors is set equal to 0. It is again necessary to check for shading through the SHADE subroutine.

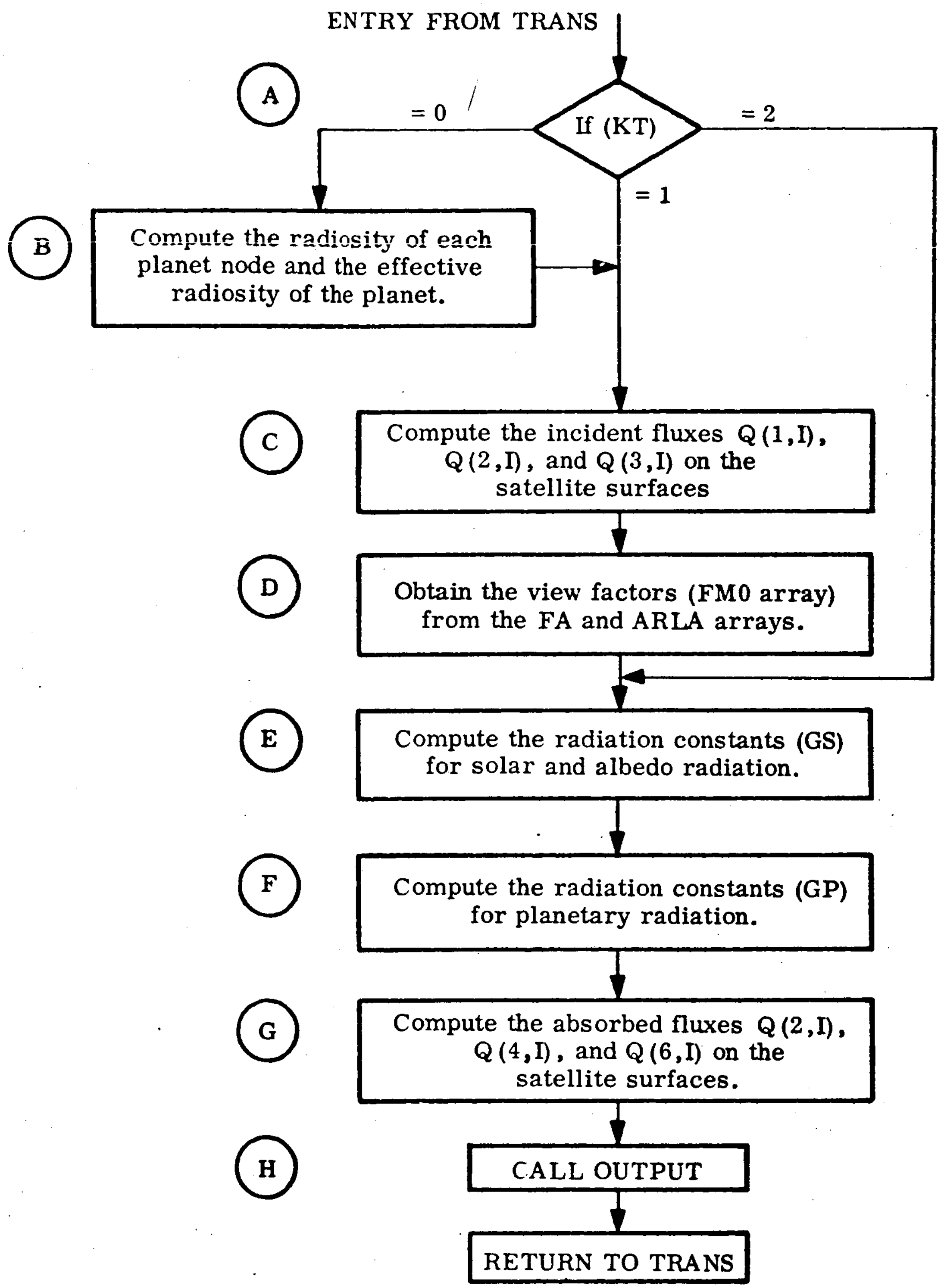

Fig. 4-9 FLUX Flow Chart

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Finally, the planet-to-sun view factors and the COST values are computed in section E, provided that either the sun or the planet has moved relative to the satellite (N1 = 1 or N2 = 1, respectively). No shading check is required in this computation.

After completion of section E, the program returns to the VIEW subroutine.

The SHADE subroutine is basically the same as the corresponding subroutine in the generalized program (see Appendix A). The restrictions are that the shading surface must be either a rectangle or trapezoid (or triangle), and one of the incremental areas must be on a satellite surface and the other on either the planet or the sun.

4.2.6 FLUX and INVERT Subroutine (See Flow Chart, Fig. 4-9)

Purpose. The FLUX subroutine computes the view factor and radiation constant matrices and the direct incident and absorbed fluxes from the data generated by MAINP and the TRANS and OMEGA subroutines. The INVERT subroutine, which is identical to the corresponding subroutine in the generalized program, performs the matrix inversions required in the radiation constant computations.

Input. Input is the same as the output from MAINP and the TRANS and OMEGA subroutines. In particular the FLUX subroutine uses NS1, NS2, NS, APLAN, TDS, TSS, and WSUN from MAINP; KT and the AS and E arrays from TRANS; and the FA, AREA, and cost arrays from OMEGA.

Output. The following quantities are computed in FLUX before transferring to OUTPUT.

- FMO(I, J): These are the view factors from surface I to surface J.
- GP(I, J): These are the radiation constants from surface I to surface J for planetary (infrared) radiation.
- GS(I, J): These are the radiation constants from surface I to surface J for solar and albedo (visible) radiation.
- Q(I, J): These are the incident and absorbed solar, albedo, and planetary fluxes on the satellite surfaces.

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Method. The method is the same as in the corresponding subroutine in the generalized program. Again, som simplification is possible because of the restricted number of surfaces and because of the assumption that absorptivity (α_s) for solar radiation is the same as for albedo radiation.

On entry from TRANS, KT is tested to see what changes have been made to the surfaces. If KT = 0 (sun or planet was changed), the radiosity of each planet node and the effective radiosity of the planet are computed (section B on flow chart). If KT = 1 (sun and planet unchanged, but one or more surfaces changed), section B is skipped and the program proceeds to sections C and D, where the new incident fluxes and the new view factors are obtained. If KT = 2 (no surfaces, and therefore no view factors, changed), the program skips to sections E, F, and G, where the radiation constants for solar and albedo radiation (GS array), the radiation constants for planetary radiation (GP array) and the absorbed fluxes are computed.

On completion of section G, the program transfers to OUTPUT. On return from OUTPUT, the program returns to TRANS.

4.2.7 OUTPUT Subroutine (See Flow Chart, Fig. 4-10)

Purpose. OUTPUT writes the results of the parametric study on the output tape.

Input. Input is the same as the output from MAINP and FLUX. ~~In~~ particular, OUTPUT uses NI, NOR, NPLAN, NS1, and the PC array from ~~MAINP,~~ and the FMO, GP, GS, and Q arrays from FLUX.

Output. The Q, FMO, GS, and GP arrays, and the run identification are written on the output tape. The run identification consists of 18 items which are described in subsection 4.3, results.

Method. NI is tested, as usual, on entry from TRANS. If NI = 0, set ICT = 0 and set up tables of Hollerith characters The appropriate Hollerith data in the run

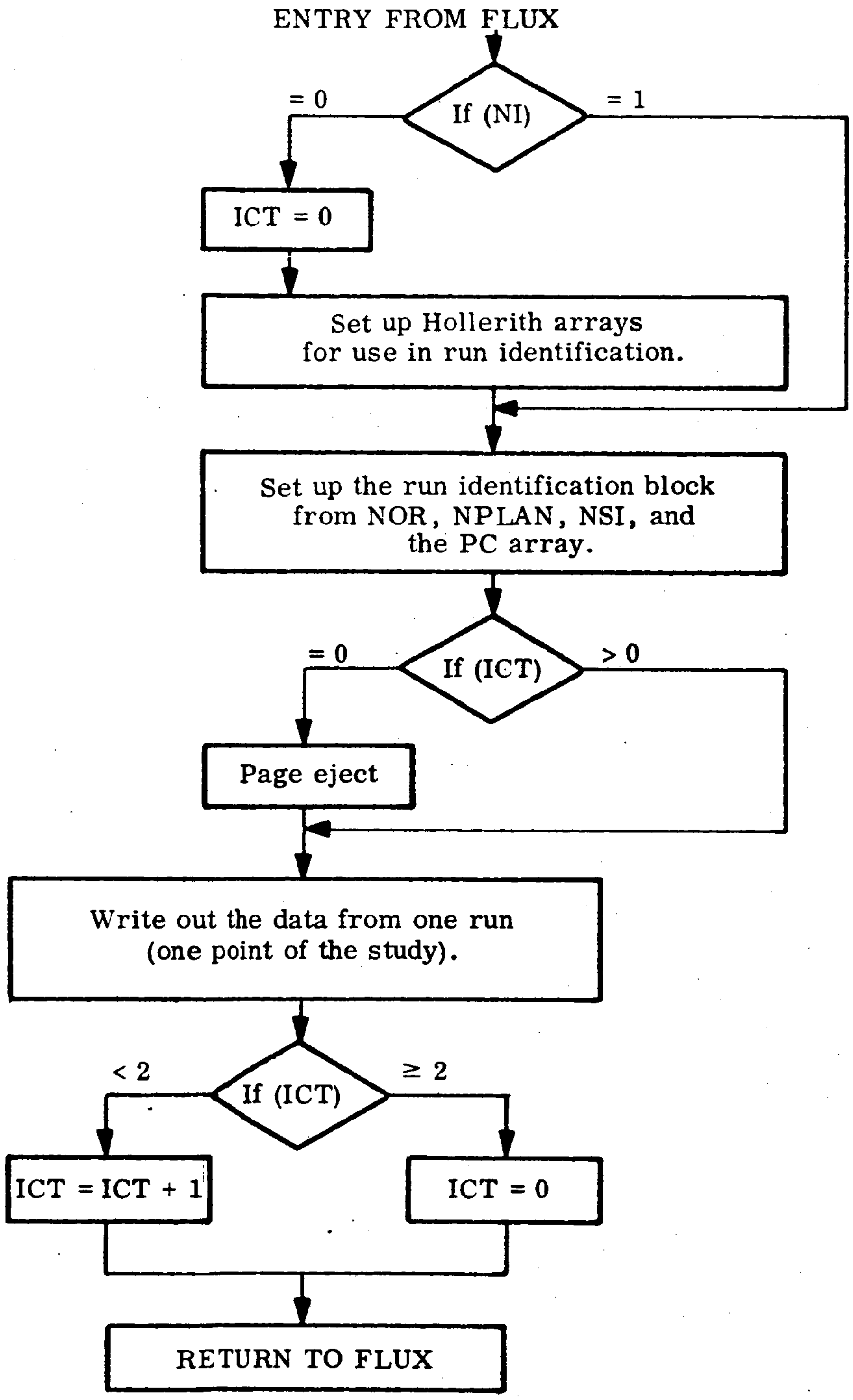

Fig. 4-10 OUTPUT Flow Chart

identification block is selected from these tables according to the current values of NOR, NPLAN, NS1, and the PC array.

After setting up the run identification block, test ICT. If ICT = 0, write the first line of output with a 1 in column 1 for a page eject. If ICT > 0, write the first line of output with a 0 in column 1 for a double space between the runs on the page.

Write out the remainder of the data for the run. After outputting the run, test ICT again. If ICT < 2, increment ICT by 1. If ICT = 2, set ICT = 0. This manipulation of ICT causes the program to output three runs per page, with a double space between the runs.

4.2.8 TRIG Package

The TRIG package used for computing trigonometric and inverse trigonometric functions is identical to the package in the generalized program.

4.3 RESULTS

The results of the parametric study are presented in separate volumes for Venus and Mars.

Each page of the results contains three points of the study, corresponding to the three values of the c/b ratio (Surface Configurations in subsection 4.2.3). The data for each point are indicated in succeeding paragraphs.

A run identification block along the right-hand margin contains the following information:

Heading	Explanation
PLANET – VENUS or MARS	Self-explanatory
ALTITUDE	The altitude of the satellite above the mean planet surface in kilometers

Heading	Explanation
ORBIT – NOON POLAR, 45 D POLAR, or TWI. POLAR	The angle β between the orbit plane and the planet-sun line (NOON indicates $\beta = 0$, 45 D indicates $\beta = 45$, TWI. indicates $\beta = 90$); see Figs. 4-2 and 4-3
ORIENTATION – SUN or PLANET	The change in the orientation of the satellite as it changes orbit position (SUN indicates that the satellite keeps the same surface facing the sun throughout the orbit; PLANET indicates that the satellite rotates as it changes orbit position so that the same surface is always facing the planet)
CONFIGURATION – 1a or 1b	The number of surfaces (1a is the two-surface configuration shown on Fig. A-1; 1b is the three-surface configuration)
POSITION – 1, 2, or 3	The direction the primary surface (surface 1) is facing (see Fig. 4-2)
ORBIT POSITION – 1 through 8	The angle between the planet-satellite line and the point in orbit nearest the planet-sun line (see Fig. 4-3)
A/B, C/B	The a/b ratio of surface 1, and the c/b ratios of surface 2 and 3 (c/b of surface 3 equals 0 in configuration 1a); see Fig. 4-1
ABSORP.	The solar absorptivity (α_s) of surfaces 1, 2, and 3
EMISS.	The low-temperature emissivity (ϵ) of surfaces 1, 2, and 3
ALPHA	The trapezoidal angle of surfaces 2 and 3 (angles α of Fig. A-1) with $\beta = \alpha$ assumed

The heat fluxes to surfaces 1, 2, and where applicable, 3 are listed across the top of each run. In this list, QS(I) is the direct incident solar flux, QS(A) is the absorbed solar flux, QR(I) is the direct incident albedo flux, QR(A) is the absorbed albedo flux, QP(I) is the direct incident planetary flux, and QP(A) is the absorbed planetary flux.

The computed view factors are listed immediately below the heat fluxes. The symbols at the left of and above the view factor array are the surface identification: S for sun, P for planet, 1 for satellite surface 1, 2 for satellite surface 2, 3 for satellite surface 3. The number at the intersection of a row and column is the view factor from the

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surface indicated at the left of the row to the surface indicated at the top of the column.

The radiation constants for solar and albedo-radiation and planetary radiation are listed in two arrays using the same format and method of identification as the view factor array. The surface identification symbols S, P, 1, 2, and 3 have been omitted at the top of these arrays.

The heat flux values computed in this study vary over about seven orders of magnitude (from about 0.00005 Btu/hr-ft^2 to about 500 Btu/hr-ft^2) depending on the satellite altitude, the angle between the planet-satellite line and the planet-sun line, the orientation of the satellite relative to the planet and sun, and the number of surfaces. The absorbed fluxes are additionally affected by the absorptivity and emissivity of the surfaces and by the view factors between the surfaces.

Figures 4-11(a) through 4-11(l) show the range of incident flux rates on the primary surface (surface 1) for $a/b = c/b = 1$. They are plotted as a function of orbit position angle at altitudes of 100 km, 1,000 km, and 10,000 km (the fluxes at 30,000 km were generally an order of magnitude lower than the fluxes at 10,000 km and were therefore too small to be plotted); and for position 1 in a noon orbit ($\beta = 0$), position 3 in a 45-deg orbit ($\beta = 45$) and position 1 in a twilight orbit ($\beta = 90$) as shown in Fig. 4-2. The orbit position angle is related to the orbit positions of Fig. 4-3 as follows: 0 deg is equivalent to orbit position 4, 30 deg to positions 3 and 5, 60 deg to positions 2 and 6, 90 deg to positions 1 and 7, and 180 deg to position 8.

In general, the effect of altitude on the fluxes is as would be expected: the planetary and albedo fluxes decrease as the altitude increases, while the solar flux is unaffected. An exception occurs in the albedo fluxes on a satellite near the terminator ($\beta = 90$ deg or orbit position angle = 90 deg). The albedo flux in this location reaches a maximum at about 0.25 to 0.75 planet radii, decreasing at higher altitudes as expected, and also decreasing at lower altitudes. The reason for this apparent anomaly is that

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at very low altitudes only a very small portion of the illuminated side of the planet is visible. As the altitude increases, more of the illuminated side of the planet becomes visible. At the lower altitudes, this increase in visibility outweighs the reduction in flux because of the increased distance from the planet.

The effect of angle between the planet-satellite line and the planet-sun line is also generally as expected. To a first approximation, the albedo flux decreases as the cosine of the orbit position angle. The Mars planetary flux also shows a cosine-like variation because of the variation in planet surface temperature.

Although the two parameters mentioned, altitude and orbit position, serve quite well to indicate the trends of the flux values, their actual magnitudes cannot be estimated without considering the orientation of the satellite and the number of surfaces involved. An indication of the effect of orientation can be obtained by comparing the flux for configuration 1a (two surfaces) at $\beta = 0$ deg, orbit position angle $= 45$ deg and the flux at $\beta = 45$ deg, orbit position angle $= 0$ deg. With $\beta = 0$ deg, the primary surface is perpendicular to the planet surface and is partially shielded by the other surfaces. With $\beta = 45$ deg, the primary surface is turned toward the planet surface and receives no shielding. The flux at the $\beta = 45$ deg point is roughly double the flux at the $\beta = 0$ deg point. The number and location of other surfaces also have a strong effect as can be seen by comparing the fluxes for configuration 1a (two surfaces) with the fluxes for configuration 1b (three surfaces). Addition of the third surface decreases the flux significantly because of the additional shielding.

4.4 DISCUSSION OF THE RESULTS

As a means of checking the validity of the parametric study, a number of hand calculations were made. The techniques and results of the hand calculation are presented in Appendix F.

The computed fluxes can be compared to the hand-calculated fluxes in either of two ways: by comparing the magnitude of the difference between computed and hand calculated values, and by comparing the percentage difference in the two values. Significant conclusions can be drawn from either method.

The percentage difference, defined as 100× (computed flux -hand calculated flux)/(hand calculated flux) gives an indication of the inherent accuracy of the methods used. Generally speaking, the largest percentage differences occur where the magnitude of the flux is very small. For example, the largest percentage difference – 104% – occurred in computing the planetary flux on surface 1 from Mars at 30,000 km and $\beta = 45$. At this point, the computed flux was 0.0237 Btu/hr-ft^2 compared to a hand-calculated value of 0.0116 Btu/hr-ft^2. These differences can be attributed mainly to inaccuracies in the hand calculations from projecting and measuring very small areas. Relatively large percentage differences also occurred when the fluxes were computed at 100 km above Mars. These differences occurred because of a break-down in the method of specifying the tolerable error in the view factors between the satellite surfaces and the planet. Subsection A.1 of Appendix A describes how the value of $N\beta$ for the planet nodes is increased until the percentage error in the surface-to-planet view factor for a "horizontal" surface is reduced below a specified amount (below 10 percent in the parametric study). Figures D-5 and D-6 of Appendix D show the percentage error in the planet view factor for "horizontal" and "vertical" surfaces as a function of altitude and $N\beta$. In general, the error in the "horizontal" surface view factor is greater than the error in the "vertical" surface view factor, and the error decreases as $N\beta$ increases. However, this is not true at 100 km above Mars. At that altitude, the percentage error in the "horizontal" surface view factor is only 1.2 percent for $N\beta = 1$, so the program assumes that $N\beta = 1$ will give the desired accuracy. That this assumption was not a good one is seen from Fig. D-6, where the error in the "vertical" surface view factor is shown to be over 28 percent. Inasmuch as surface 1 is a "vertical" surface in the cases that are being compared, there is an error of about 28 percent in the Mars 100-km computed fluxes. This source of error does not apply to the other altitudes.

The magnitude of the difference between the computed and hand-calculated fluxes gives an indication of the effect any inaccuracies in the method may have on the satellite temperature. An inaccuracy of, say, 10 percent would be tolerable if the heat fluxes were of the order of 0.01 Btu/hr-ft^2 because an error of 0.001 Btu/hr-ft^2 is insignificantly small. On the other hand, an inaccuracy of 10 percent in computing a flux of the order of 100 Btu/hr-ft^2 would produce an error of 10 Btu/hr-ft^2, which could be significant in predicting the satellite temperature level. As with percentage difference, the largest differences in magnitude occurred in the Mars 100-km cases. An addition to these differences, which were discussed above, there is some disagreement in the Venus albedo fluxes. The incident albedo flux on a "vertical" surface above the subsolar point can be computed from an exact equation.

At 100 km above Venus, the exact equation gives 241.5 Btu/hr-ft^2 incident upon surface 1 (the vertical surface); the incident flux by the hand calculation technique is 270 Btu/hr-ft^2; and the computed incident flux is 246 Btu/hr-ft^2. This would indicate that the difference between computed and hand-calculated albedo fluxes for Venus is due primarily to errors in the hand-calculation procedure rather than in the computation for the parametric study.

Section 5
RELATED LMSC EXPERIENCE AND RECOMMENDATIONS FOR FUTURE STUDY

5.1 COMPUTER PROGRAMS

The solution of satellite and spacecraft temperature control problems includes the development of specialized computer programs for performing the complex mathematical analyses involved. These programs may be grouped into three broad categories:

1. Heat flux programs for determining the solar, albedo, and planetary fluxes incident upon the satellite
2. Radiant interchange programs for computing view factors and radiation constants
3. Thermal analyzer programs for computing the satellite temperature history

A number of programs have been developed at LMSC to solve specific problems in each of these broad categories.

In the category of heat flux programs, the Generalized Heat Flux Program represents an integration of a long series of programs designed for the solution of both general and specific problems. Among the problems resolved through the development of previous specific computer programs are:

1. Determination of the fluxes incident on a medium life spin-stabilized satellite in an elliptical orbit about the earth. In this, it was first necessary to determine the location and orientation of the satellite up to six months after launch, considering the rotation and precession of the satellite orbit and the apparent motion of the sun, and then to determine the heat fluxes, averaged over one spin cycle, for the life of the satellite. The problem was resolved through development of a computer program that uses the satellite orbit dynamics equations and solar ephemeric data to determine the location and orientation of the satellite, and a version of the method of view factors (also used in the Generalized Heat Flux Program) to obtain the solar, albedo, and planetary fluxes on the satellite.

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2. Determination of the effect of cloud cover, monthly variations in cloud cover, and lunar radiation on a satellite in an elliptical orbit about earth. Available data on the monthly variations in cloud cover and its effect on the earth's albedo and effective surface temperature, and data on the lunar albedo and surface temperature were combined in a computer program that computes the resultant variation in heat fluxes.

Radiant interchange programs are of high importance in thermodynamic analysis, because of the important role of radiation in the satellite heat balance, and because of the mathematically difficult relationships that exist between radiating surfaces. Two kinds of programs are required in this category; view factor programs for computing the geometric view factors between surfaces, especially in complex geometries where the view factors are reduced by shielding from other surfaces; and radiation-constant programs which solve the equations of Poljack, Hottel, or Gebhart to obtain the net radiation interchange between surfaces. Advanced versions of both kinds of programs have been incorporated in the Generalized Heat Flux Program.

The whole purpose of the preceding two categories of programs is to provide inputs to thermal-analyzer programs which compute the actual temperature history of the satellite. Thermal-analyzer programs, based on the solution of an R-C electrical network analogous to the heat transfer network have been under continual development at LMSC for several years. These programs in addition to solving the basic R-C network, contain a wide variety of functions for computation of special mathematical and thermodynamic relationships.

At the initiation of the Heat Flux Study, a large number of programs were available for solution of specific heat flux and radiant interchange problems. However, there was not, at that time, a program of sufficient generality to provide the thermodynamics analyst with a simple tool capable of solving the entire heat flux radiant interchange problem. It was necessary for the analyst to select the computer program that could best solve the most important aspects of his problem, accepting the fact that less important aspects would be ignored. The Generalized Heat Flux Program represents

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a major step toward the development of this much needed general program. There remain, however, a number of problems that the Generalized Heat Flux Program is not capable of handling. As a logical extension of the Heat Flux Study, the following areas for future study are recommended. Incorporation of these proposed developments into the Generalized Heat Flux Program would go a long way toward achievement of a true general heat flux radiant interchange program.

5.2 EXTENSIONS OF THE GENERALIZED HEAT FLUX PROGRAMS

The versatility of the present heat flux programs could be extended to solve one or more of the following problems that will occur during a satellite's travel around the Earth or other planets and during the satellite's interplanetary travel.

5.2.1 The Calculation of Incident and Absorbed Heat Fluxes on a Satellite that is Neither Planct Nor Space Oriented

This mode of orientation is often referred to as a deactivated or a tumbling orientation in which the satellite has a constant pitch, yaw, or roll rate as it moves around the planet. These rates would be part of the input data for this mode of flight. The suggested definitions of these rates would be as follows:

- Yaw rate, $\Delta\phi/\Delta t$, the rate of change of the yaw angle with orbit time or position, where ϕ is the angle the X" Y" axis is rotated about the Z" axis.
- Pitch rate, $\Delta\Psi/\Delta t$, the rate of change of the pitch angle with orbit time or position, where Ψ is the angle the X_p Z" axis are rotated about the Y_p axis.

  NOTE

  An alternate method of defining pitch is: the angle between the projection of the X axis on the orbit plane and the X" axis.
- Roll rate, $\Delta\omega/\Delta t$, the rate of change of the roll angle with orbit time or orbit position, where ω is the angle the Y_p Z_c axis is rotated about the X axis.

The pitch, yaw, and roll angles are shown in Fig. 5-1 where the Orbit Plane Coordinate System (X", Y", Z") is taken for the planet-oriented coordinate system shown in Fig. B-4. The X, Y, Z system is the Central Coordinate System of the satellite. The horizontal plane is perpendicular to the planet radius vector.

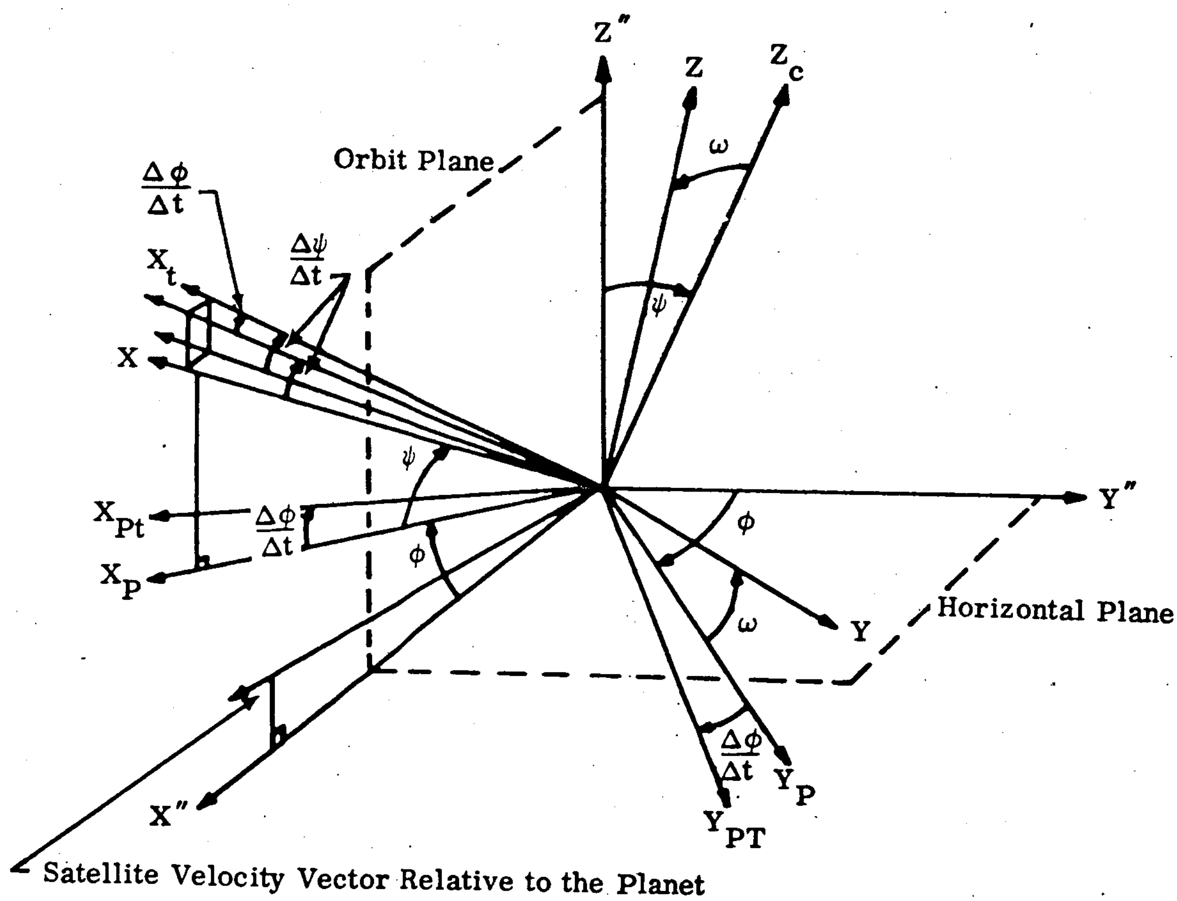

Fig. 5-1 Yaw, Pitch, and Roll Rates

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5.2.2 The Calculation of Incident and Absorbed Solar Heat Flux on a Spacecraft in a Transfer Orbit Between Planets

This computer program would be used to determine the solar radiation on a satellite that is unaffected by the planets in our solar system. The satellite is assumed to be in an orbit around the sun or in a trajectory between the planets. Perihelion and aphelion could be input to the program so that a portion of this ellipse could be considered as the path of the spacecraft during "free-flight". Alternately, the exact equations of the trajectory could be programmed; the program will then calculate the distance to the sun, and the spacecraft orientation with respect to the sun for use in further calculations.

With the elliptical orbit approach, the spacecraft could be sun oriented, space oriented (such as the First Point in Aries), or possibly earth oriented. Perihelion and aphelion could be changed at a point in the transfer orbit to account for the added trajectory correction velocity. Also, during this correction maneuver, heat fluxes can be calculated for the reoriented spacecraft.

5.2.3 The Calculation of Incident and Absorbed Heat Fluxes on Cylinders, Cones, and Spheres as Surface Geometric Configurations

The present generalized heat flux computer program has the capability to analyze shading of surfaces described by rectangles, disks, and triangles. However, equations that describe a cylinder, a cone, a sphere, or any part of these geometric configurations, can be written and solved. These new geometric configurations will also utilize the shading check routine. They will be input to the computer, and output in a manner similar to the present handling of rectangles, disks, and triangles.

5.2.4 The Calculation of the Averaged Incident and Absorbed Heat Fluxes on a Shaded Spinning Satellite in an Orbit About a Planet

This can be accomplished by assuming that the spinning surface approximates a sphere, cylinder, or a cone. However, this approximation becomes quite gross when a spinning cube or a tetrahedron is considered, especially when the surfaces are shaded.

The actual heat fluxes would be more accurately calculated by using the actual surface configurations – for example, flat plates and the shading surfaces in a specific position, and then calculate the heat fluxes. Subsequently, the surfaces are rotated through a specified angle about the spin axis and the heat fluxes are recalculated. This rotation and flux calculation would continue for the entire 360° about the spin axis of the satellite. Then the sum of the fluxes would be averaged for the surfaces.

Average heat fluxes can be used when the rotation rate of the spinning vehicle and the thermal capacity of the vehicle skin are such that the actual skin temperature variation throughout one revolution is small. For example, studies have indicated that in an Earth orbit, 1 rpm may give a temperature variation of 5° F on solar cells during one revolution.

5.2.5 Provision for Non-Cosine Distribution of Planet Surface Temperature on the Illuminated Side

The planet surface temperature on the illuminated side does not necessarily vary as the cosine of the angular distance from the subsolar point. Provision can be made to use equations, such as a power series, to describe the angular temperature distribution. Description of the temperature distribution in tabular form is also possible, but does not utilize the computer program as efficiently as would be done by using an equation.

5.3 METHODS OF CALCULATING RADIATION HEAT TRANSFER VARIABLES

5.3.1 Radiation Interchange Factors

The Generalized Heat Flux Program supplies heat fluxes to the exterior surfaces of the satellite. During the performance of the thermal analyses of a spacecraft, however, the thermal radiation between groups of internal equipment must generally also be determined. This entails the determination of the radiation interchange factor between each pair of surfaces. These radiant interchange factors are calculated from the matrix form of the radiant interchange equations which use the surface areas, emissivities, and geometric view factors.

The suggested computer program would be an extension of existing programs in use at LMSC and would handle up to 100 different surfaces in an enclosure. The surface geometric configurations would be the rectangle, disk, triangle, cylinder, cone, or sphere with provisions for the partial or total blockage of the geometric view factor between two surfaces by an intervening surface. This is the method used in the present heat flux program. The output would consist of calculated surface areas, the FA matrix, the FA matrix and the RADK factor, which is σ FA. Punched card output for ready use in a thermal analyzer in any desired format can be provided.

5.3.2 Mathematical Approach

A study of mathematical methods to analyze highly specular exterior satellite surfaces is suggested. This is a necessary area of study for more accurate predictions of satellite temperature and its control for highly reflective surfaces such as gold or aluminum. It is known that these surfaces reflect incident radiative energy in a specular manner rather than diffusely as is assumed in the generalized heat flux program equations. The logical initiation of the mathematical approach would be the analysis of radiation from the sun, which approaches a point source, and its specular reflections from the primary surface to one or two secondary satellite surfaces. Methods of attack for more complex arrangements would be evaluated as part of such a study.

Section 6
REFERENCES

1. JPL Request for Proposal No. 3164, Heat Flux Study, 28 June 1963

2. JPL Interoffice Memo, from W. A. Hagemeyer to R. P. Thompson, "Discussion of Parameters and Constraints for an Orbiter Heat Flux Study," 23 Oct 1963

3. Heat Flux Study Contract Document, Contract No. 950674 (LMSC/A601500), 16 Jan 1964

4. D. C. Hamilton and W. R. Morgan, "Radiant Interchange Configuration Factors," NACA Technical Note 2836, Dec 1952

Appendix A

PROGRAM EQUATIONS

A.1 THE SATELLITE ORBIT EQUATIONS

The calculations for these equations were performed prior to the calculation of the geometric view factors and heat fluxes outlined in subsection A.2.

A.1.1 Beta and Alpha(s) angles

The calculated Beta and Alpha(s) angles (β and α_s) for the satellite orbit plane relative to the sun are as shown in Figs. A-1 and A-2.

A.1.2 Orientation of Planet and Sun Relative to the Central Coordinate System (X,Y,Z)

The Orbit Plane Coordinate System (X'', Y'', Z'') is shown in Fig. A-3 for a space-oriented satellite and in Fig. A-4 for a planet-oriented satellite. To rotate to the X'', Y'', Z'' coordinate system to the X, Y, Z coordinate system, the R matrix is defined in terms of the initial phi, psi, and omega (ϕ_I, ψ_I, ω_I) as follows:

$$R(1,1) = \cos\psi_I \cos\phi_I$$

$$R(1,2) = -\sin\omega_I \sin\psi_I \cos\phi_I + \cos\omega_I \sin\phi_I$$

$$R(1,3) = -\cos\omega_I \sin\psi_I \cos\phi_I - \sin\omega_I \sin\phi_I$$

$$R(2,1) = -\cos\psi_I \sin\phi_I$$

$$R(2,2) = \sin\omega_I \sin\psi_I \sin\phi_I + \cos\omega_I \cos\phi_I$$

$$R(2,3) = \cos\omega_I \sin\psi_I \sin\phi_I - \sin\omega_I \cos\phi_I$$

$$R(3,1) = \sin\psi_I$$

$$\beta = \beta + \Delta\beta - \Delta\beta$$

$$\beta = \sin^{-1}\left(\sin i \sin \Omega\right) - \sin^{-1}\left(\cos i \tan \delta\right) \qquad (1a)$$

$$\alpha_s = \alpha_p + \theta_p + \Delta\theta$$

$$= \alpha_p + \tan^{-1}\left(\cos i \tan \Omega\right) + \tan^{-1}\left\{\tan \delta \cos\left[\sin^{-1}\left(\frac{\cos i}{\cos \delta}\right)\right]\right\} \qquad (2a)$$

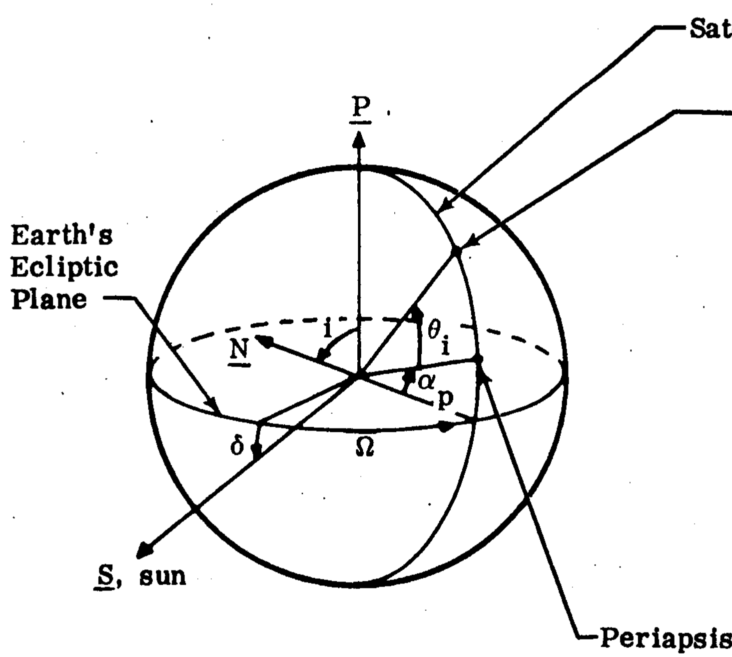

Fig. A-1 Orbit Plane

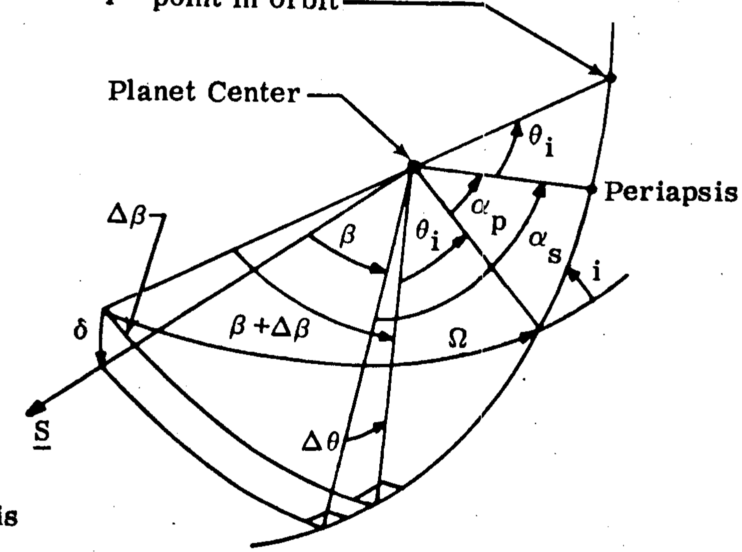

Fig. A-2 Orbit Plane Detail

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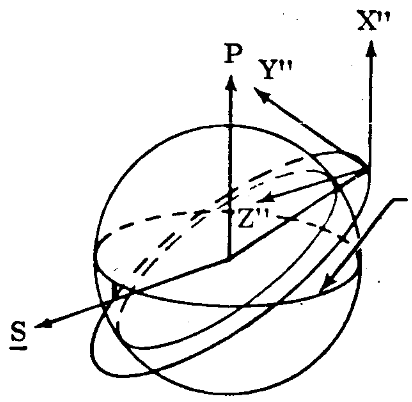

Fig. A-3
Space-Oriented Satellite

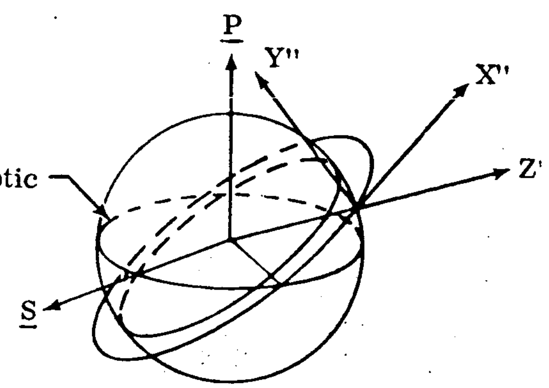

Fig. A-4
Planet-Oriented Satellite

These values are used to locate the Z_p axis and the Z_s axis:

$$\Omega_T = \Omega + \Delta\Omega$$

$$\Omega_T = \Omega + \tan^{-1}\left[\cos i \tan\left(\theta_i + \alpha_p\right)\right]$$

$$\sigma = \sin^{-1}\left[\sin i \sin\left(\theta_i + \alpha_p\right)\right]$$

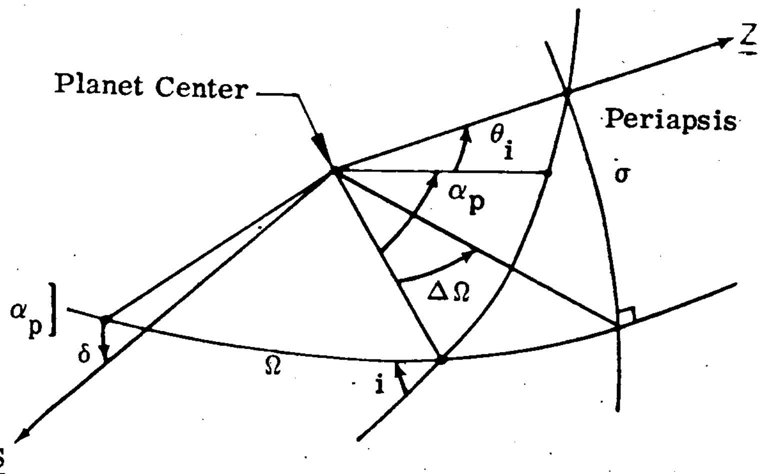

Fig. A-5 Space-Oriented Orbit Plane Detail

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$$R(3,2) = \sin \omega_I \cos \psi_I$$

$$R(3,3) = \cos \omega_I \cos \psi_I$$

Then

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = [R]^{-1} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

However, it is first necessary to define the +Z axis of the sun and the planet in terms of the X'' , Y'' , Z'' axis depending on the orientation of the satellite.

<u>Planet-oriented satellite.</u> The + Z axis is defined as follows:

Z_s = +Z axis of the sun for the i^{th} satellite position

Z_p = +Z axis of the planet for the i^{th} satellite position

$\theta_T = \alpha_s + \theta_i$ (see Fig. A-2)

$$Z_s = [-\sin \theta_T \cos \beta \;\; \sin \beta \;\; \cos \theta_T \cos \beta] \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

Or, in terms of the X , Y , Z coordinate system,

$$Z_s = \begin{bmatrix} -R(1,1) \sin \theta_T \cos \beta & - R(1,2) \sin \theta_T \cos \beta & - R(1,3) \sin \theta_T \cos \beta \\ R(2,1) \sin \beta & R(2,2) \sin \beta & R(2,3) \sin \beta \\ R(3,1) \cos \theta_T \cos \beta & R(3,2) \cos \theta_T \cos \beta & R(3,3) \cos \theta_T \cos \beta \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Also,

$$Z_p = [R(1,3) \; R(2,3) \; R(3,3)] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Space-oriented satellite. The +Z axis is defined as follows:

$$Z_p = \left[\sin\sigma \; - \sin\Omega_T \cos\sigma \; \cos\sigma\cos\Omega_T\right] \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

$$Z_s = [-\sin\delta \; 0 \; \cos\delta] \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

Or, in terms of the X , Y , Z coordinate system,

$$Z_p = \begin{bmatrix} R(1,1)\sin\sigma & R(1,2)\sin\sigma & R(1,3)\sin\sigma \\ -R(2,1)\sin\Omega_T\cos\sigma & -R(2,2)\sin\Omega_T\cos\sigma & -R(2,3)\sin\Omega_T\cos\sigma \\ R(3,1)\cos\sigma\cos\Omega_T & R(3,2)\cos\sigma\cos\Omega_T & R(3,3)\cos\sigma\cos\Omega_T \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$Z_s = \begin{bmatrix} -R(1,1)\sin\delta & -R(1,2)\sin\delta & -R(1,3)\sin\delta \\ 0 & 0 & 0 \\ R(3,1)\cos\delta & R(3,2)\cos\delta & R(3,3)\cos\delta \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

A.1.3 Geocentric Angles of Shadow Points

As shown in Fig. A-6, a shadow point occurs when $\cos\alpha_1 + \cos Z_1 = 0$. These two unknown angles are found by an iterative process in the SHADOW subroutine.

From spherical trigonometry and identities, the following equation is developed and solved to determine the shadow points:

$$SZ = \cos(Z) = \cos\beta\cos\theta$$

$$90° < Z_1 < 270°$$

RP = satellite altitude at perigee

RAD = radius of satellite (planet radius + altitude) at any point in the satellite orbit

P = planet radius

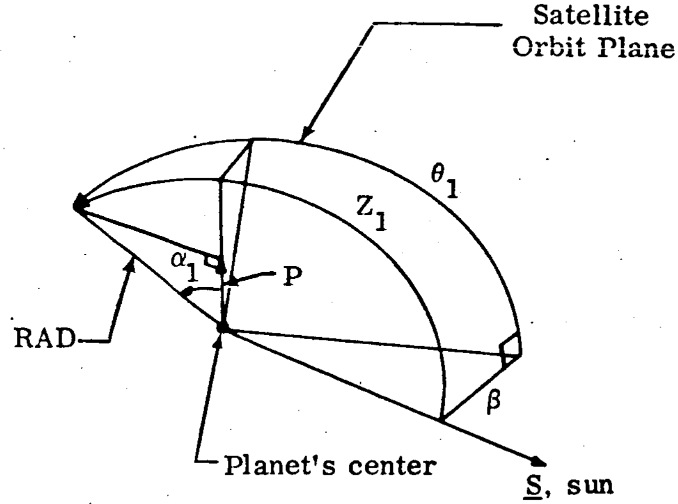

Fig. A-6 Shadow Point

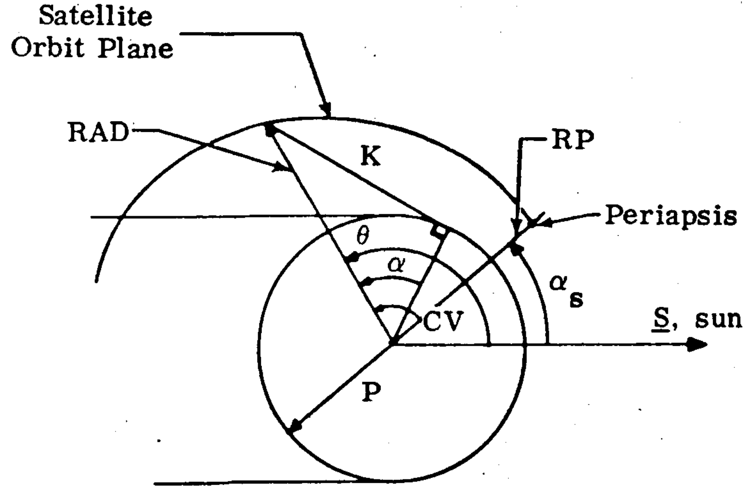

Fig. A-7 Geocentric Angles

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Therefore,

$$\cos Z = -\sin(Z - 90°) = -\sin \alpha$$

or the desired result becomes

$$\cos \alpha_1 + \cos Z_1 = 0 \Rightarrow -\sin \alpha_1 + \sin \alpha_1 = 0$$

From Fig. A-7, $\sin \alpha = K/RAD = EN$

$$EN = \sqrt{1.0 - \left(\frac{P}{RAD}\right)^2}$$

From the true eliptical equations, this can be written as

$$EN = \sqrt{1.0 - \left[\frac{P[1.0 + E\cos(CV)]}{R1(1.0 + E)}\right]^2}$$

where R1 = RP + P
E = orbit eccentricity

A.1.4 The True Eliptical Orbit Equations

The following true eliptical equations refer to Fig. A-8 and are used to calculated the shadow points (subsection A.1.3), the orbit period, eccentricity, and orbit time from periapsis:

Semimajor axis, radius, $A = RA + RP + 2\,R_o/2$

Eccentricity, $E = RA - RP/2A$

Orbit period, $P = 2\pi\sqrt{A^3/R_o^2\,G_0}$

Radius vector, $R = A(1 - E^2)/[1 + (E)\cos\theta]$

Eccentric anomaly, $EG = \cos^{-1}(A - R/AE)$

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Time from periapsis, $T = P/2\pi$ [EG - (E)s in EG]

Altitude of satellite, $H = R - R_o$

where

R_o = planet radius

RA = altitude at apoapsis

RP = altitude at periapsis

The true elliptical equations assume that:

1. The planet is spherical.
2. There is no atmospheric drag.
3. The gravitational constant of the planet is g_0 , is located at the center of planet, and is the only g acting on the satellite.

A.1.5 Planet View Factor Error

This routine is calculated in the VIEW subroutine to determine the number of elements that each planet node is to be divided into. "Elements" and "nodes" are defined in Appendix A, subsection A.2. The view factor accuracy of the finite difference approximation used in this computer program is a function of the satellite altitude and the number of elements that each of the 36 planet nodes are divided into. A large number of elements for each node would give a high degree of view factor accuracy for most altitudes, but the required computer run time would be correspondingly high to calculate the view factor for each of these elements.

Therefore, this routine uses the altitude of the satellite at the i^{th} point in orbit and the desired accuracy of the view factor input by the program user to calculate the number of elements that each planet node is to be divided into.

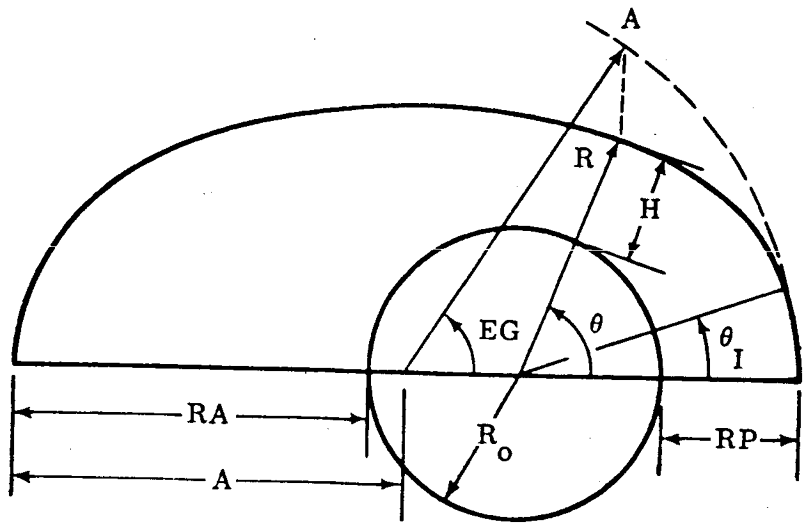

Fig. A-8 True Elliptical Orbit

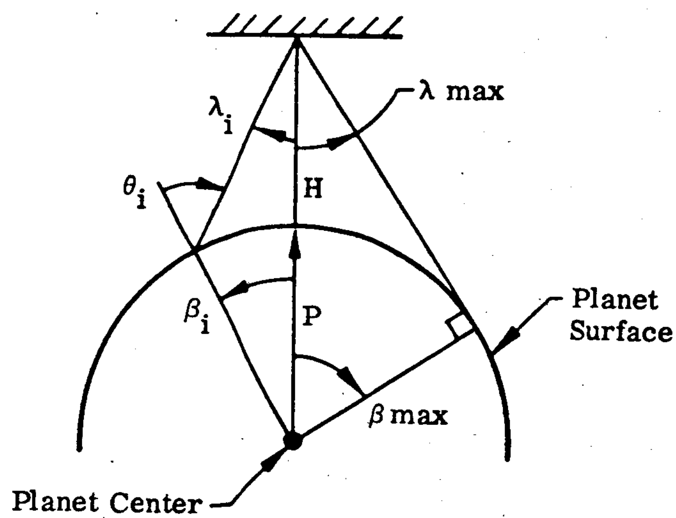

Fig. A-9 Planet View Factor

The integrated view factor of a unit area flat plate facing the planet (Fig. A-9) is

$$F_{1-p} = \frac{1}{A_1} \int_{A_1} \int_{A_p} \frac{\cos\lambda \cos\phi}{\pi r^2} \, dA_1 \, dA_p = \frac{P^2}{(H + P)^2}$$

If this equation is approached by the finite difference method, the following equation results

$$F'_{1-p} = 2\pi \left[\sum_{i=1}^{NBT} \frac{\cos\phi_i \cos\lambda_i}{\pi r_i^2} \left(P^2 \sin\beta_i \right) \Delta\beta \right]$$

where

$\Delta A_p \; = 2\pi P^2 \sin\beta_i (\Delta\beta)$

NBT $= (N\beta)(NV\beta) = N\beta \times 3$

$N\beta$ = number of elements in each node in the β direction

$NV\beta$ = number of nodes in the β direction (defined as 3 for the planet)

$V_i^2 = (H + P)^2 + P^2 - 2(H + P)(P) \cos\beta_i$

$N\beta$ continues to increase until

$$ERR > \% \text{ error}$$

where:

$$\% \text{ error} = \frac{|F_{1-P} - F_{1-P}|}{F_{1-P}} \, 100$$

ERR = percentage error input by the program user

Subsection D.2 of Appendix D contains graphs of the number of $N\beta$'s that this routine will divide each planet node into for various altitudes.

A.2 THE HEAT FLUX CALCULATIONS

This subsection provides a summary of the basic mathematical equations and assumptions used for every i^{th} position of the satellite in orbit to calculate the heat flux at that time. In general, the equations are presented in the same order in which they appear in the Main Program and the subroutines.

The succeeding subsection, A.2.1, Input Quantities, refers to the quantities used in the computing process and not the quantities input by the program user.

A.2.1 Input Quantities

Input consists of a description of the dimensions, location, orientation, and surface properties of each heat transfer surface; the number and distribution of heat transfer nodes on each surface; and the number and distribution of finite difference elements on each node. (A surface here is defined as a geometrical figure such as a rectangle, disk, trapezoid, or sphere or a portion of such a figure. A node is the portion of a surface that is assumed to react as a unit in heat transfer calculations. An element is the portion of a node that is taken as a unit in the finite difference view factor calculation.)

<u>Surface dimensions</u>. Each surface is input in terms of its own coordinate system (indicated by a prime). The following dimensions are input (see Fig. A-10):

ILK = surface type

±1 – reactangle ±2 – disk ±3 – trapezoid ±6 – sphere	Positive values indicate the direction of the surface normal to the direction of the +1′ axis, negative values in the direction of the -1′ axis

α = distance (or angle) from origin or principal axis

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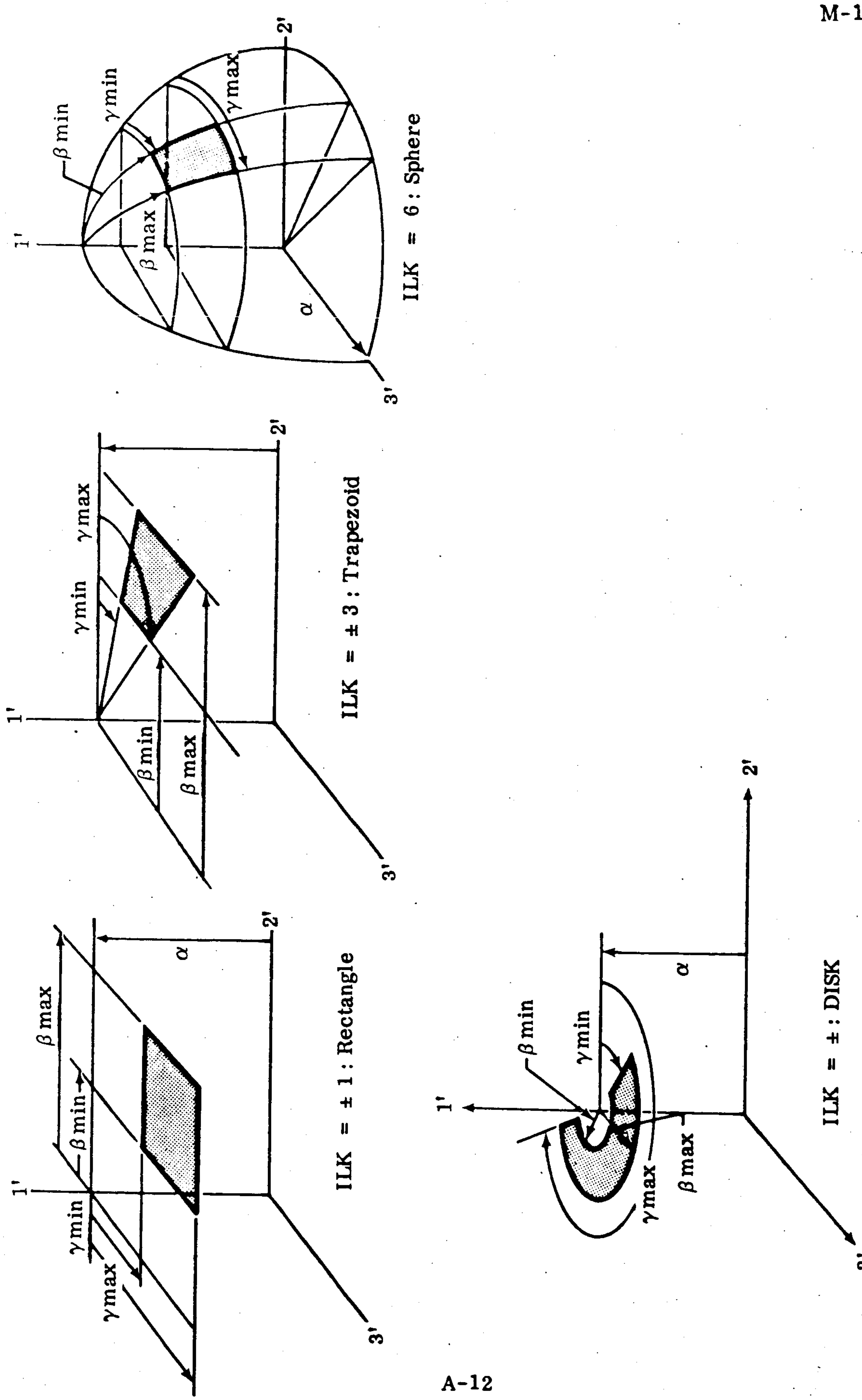

Fig. A-10 Surface Dimensions

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β_{min} = minimum distance (or angle) in β direction

γ_{min} = minimum distance (or angle) in γ direction

β_{max} = maximum distance (or angle) in β direction

γ_{max} = maximum distance (or angle) in γ direction

Surface location and orientation. The location and orientation of each surface coordinate system (3′ , 2′ , 1′) are specified in terms of a central coordinate system (3, 2, 1). The following quantities are required (see Fig. A-11):

R1 = distance from origin of central coordinates to origin of primed coordinates in direction of +1 axis

R2 = same distance in direction of +2 axis

R3 = same distance in direction of +3 axis

ϕ = yaw angle (the angle the 3 2 axes are rotated about the 1 axis, positive in the clockwise direction when viewed from the +1 axis)

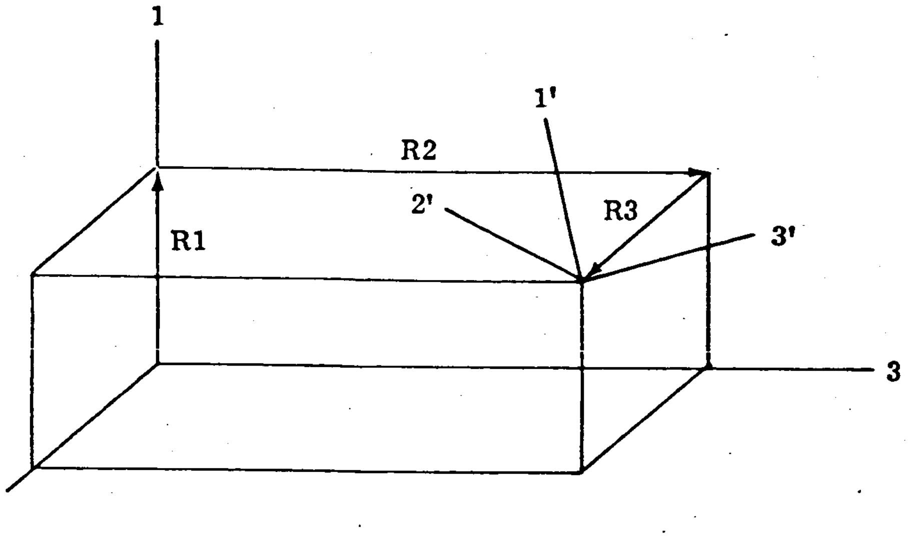
ψ = pitch angle (the angle the 3p 1 axes are rotated about the 2p axis, positive in the clockwise direction when viewed from the 2p axis)

ω = roll angle (the angle the 2p 1c axes are rotated about the 3′ axis, positive in the counterclockwise direction when viewed from the +3′ axis)

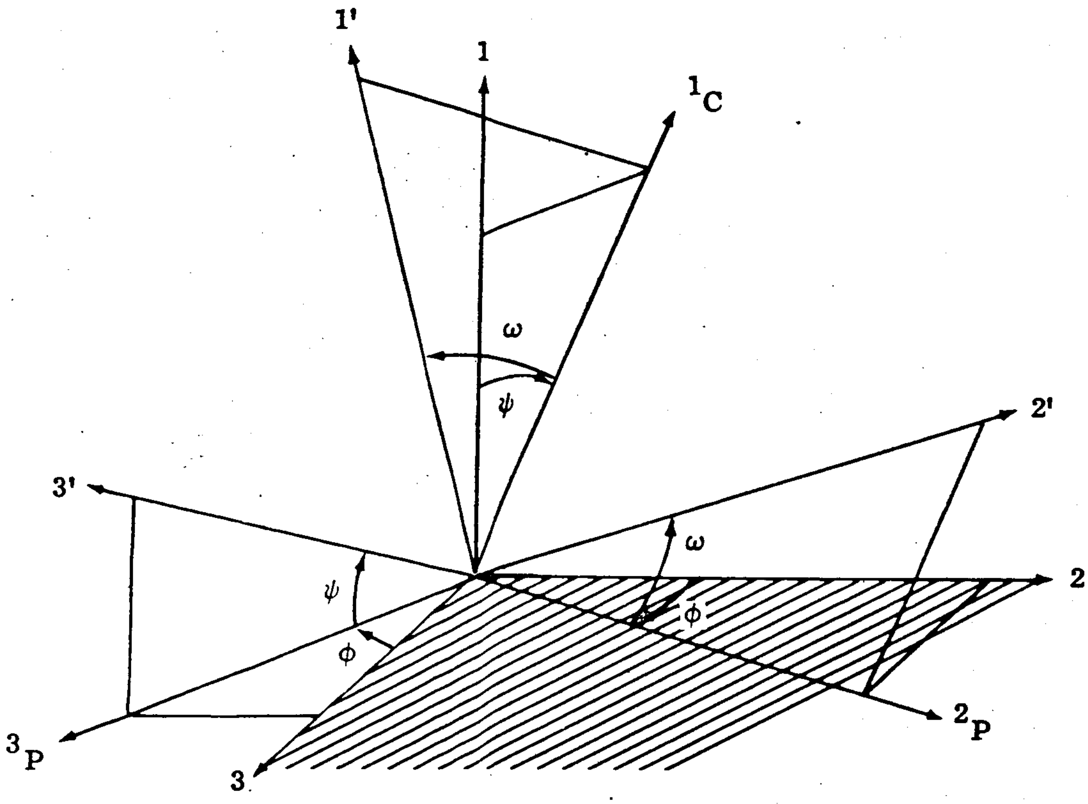
Node specification. Each surface may be divided into nodes by specifying NVβ and NVγ (see Fig. A-12), where

NVβ = number of nodes in β direction

NVγ = number of nodes in γ direction

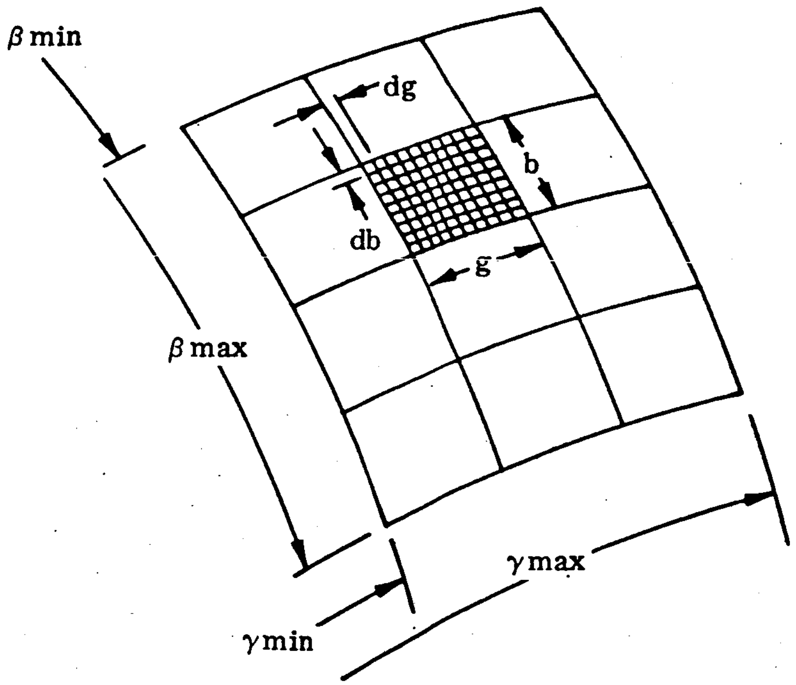


(a) Location: R1, R2, R3



(b) Orientation: ϕ, ψ, ω

Fig. A-11 Surface Location and Orientation



b = width of node in β direction = $(\beta\max - \beta\min)/NV\beta$

g = width of node in γ direction = $(\gamma\max - \gamma\min)/NV\gamma$

ab = width of element in β direction = $b/N\beta$

dg = width of element in γ direction = $g/N\gamma$

$NV\beta = 4$

$NV\gamma = 3$

$N\beta = 6$

$N\gamma = 8$

$NV\beta \times NV\gamma$ = number of nodes/surface = 12

$N\beta \times N\gamma$ = number of elements/node = 48

$(N\beta \times N\gamma) \times (NV\beta \times NV\gamma)$ = number of elements/surface = 576

Fig. A-12 Node and Element Distribution

Element specification. The nodes of a surface are divided into elements for the finite difference view factor calculation by specifying $N\beta$ and $N\gamma$ (see Fig. A-12), where

$N\beta$ = number of elements in β direction

$N\gamma$ = number of elements in γ direction

The division into elements applies to every node of the surface.

Surface properties. The radiation properties α_s, α_a, and ϵ are specified for each satellite surface:

α_s = solar absorptivity

α_a = albedo absorptivity

ϵ = infrared emissivity = infrared absorptivity

This method of dividing all surfaces into nodes and elements includes the sun and the planet surfaces. The sun is considered as a disk of one node and one element. The planet is considered as 36 nodes, 12 in the γ direction and 3 in the β direction. Each of these planet nodes has one element in the γ direction but a variable number of elements in the β direction as calculated by a routine in VIEW, as explained in Appendix A, subsection A.1.4. The solar and planet surfaces are considered as black bodies.

A.2.2 Position and Area Vectors

The first step of the computation is to obtain the position (POS) and area (ARA) vectors for each element. Vectors are defined as follows:

POS(N,1) = 1-axis component of position vector of Nth element
POS(N,2) = 2-axis component of position vector of Nth element
POS(N,3) = 3-axis component of position vector of Nth element
ARA(N,1) = 1-axis component of area vector of Nth element
ARA(N,2) = 2-axis component of area vector of Nth element
ARA(N,3) = 3-axis component of area vector of Nth element

The values of POS(N,M) and ARA(N,M) are computed from the following:

$$
\begin{aligned}
POS(N,1) &= P(3,3)\times B1 + P(3,2)\times B2 + P(3,1)\times B3 + R1_s \\
POS(N,2) &= P(2,3)\times B1 + P(2,2)\times B2 + P(2,1)\times B3 + R2_s \\
POS(N,3) &= P(1,3)\times B1 + P(1,2)\times B2 + P(1,1)\times B3 + R3_s \\
ARA(N,1) &= P(3,3)\times G1 + P(3,2)\times G2 + P(3,1)\times G3 \\
ARA(N,2) &= P(2,3)\times G1 + P(2,2)\times G2 + P(2,1)\times G3 \\
ARA(N,3) &= P(1,3)\times G1 + P(1,2)\times G2 + P(1,1)\times G3
\end{aligned}
$$

where P(I,J) is defined as the matrix rotation of the 3, 2, 1 coordinate system to the 3′, 2′, 1′ coordinate system in Fig. A-11(b).

$$
\begin{bmatrix} 3' \\ 2' \\ 1' \end{bmatrix} = [P] \begin{bmatrix} 3 \\ 2 \\ 1 \end{bmatrix}
$$

$$
\begin{aligned}
P(1,1) &= \cos\psi_s \times \cos\varphi_s \\
P(2,1) &= \cos\psi_s \times \sin\varphi_s \\
P(3,1) &= \sin\psi_s
\end{aligned}
$$

$$
\begin{aligned}
P(1,2) &= \cos\omega_s \times \sin\varphi_s - \sin\omega_s \times \cos\psi_s \cos\varphi_s \\
P(2,2) &= \cos\omega_s \times \cos\varphi_s - \sin\omega_s \times \sin\psi_s \times \sin\varphi_s \\
P(3,2) &= \sin\omega_s \times \cos\varphi_s
\end{aligned}
$$

$$
\begin{aligned}
P(1,3) &= -\sin\omega_s \times \sin\varphi_s - \cos\omega_s \times \sin\psi_s \cos\varphi_s \\
P(2,3) &= \sin\omega_s \times \cos\varphi_s \times \cos\omega_s \times \sin\psi_s \times \sin\varphi_s \\
P(3,3) &= \cos\omega_s \times \cos\psi_s
\end{aligned}
$$

where B1, B2, B3, G1, G2, G3 are defined as follows for the various surface types:

ILK = ±1 (Rectangle)

$B1 = \alpha_s$	$G1 = \pm db \times dg$
$B2 = \beta_s$	$G2 = \overline{0}$
$B3 = \gamma_s$	$G3 = 0$

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ILK = ±1 (Disk)

$B1 = \alpha_s$ $\qquad G1 = \pm db \times \cos^2 \gamma \times \beta \times dg \pm dg^2 \times \beta \times \sin^2 \gamma$

$B2 = \alpha_s \times \cos \gamma$ $\qquad G2 = 0$

$B3 = \beta \times \sin \gamma$ $\qquad G3 = 0$

ILK = ±3 (Trapezoid)

$B1 = \alpha_s$ $\qquad G1 = \pm db \times dg \times \beta / \cos^2 \gamma$

$B2 = \beta$ $\qquad G2 = 0$

$B3 = \beta \times \tan \gamma$ $\qquad G3 = 0$

ILK = ±6 (Sphere)

$B1 = \alpha_s \times \cos\beta$ $\qquad G1 = \pm db \times dg \times \alpha_s^2 \times \sin \beta \times \cos \beta$

$B2 = \alpha_s \times \sin\beta \times \cos\gamma$ $\qquad G2 = \pm db \times dg \times \alpha_s^2 \times \sin^2 \beta \times \cos \gamma$

$B3 = \alpha_s \times \sin\beta \times \sin\gamma$ $\qquad G3 = \pm db \times dg \times \alpha_s^2 \times \sin^2 \beta \times \sin \gamma$

and where

β = distance (or angle) to center of element in β direction

γ = distance (or angle) to center of element in γ direction

db = width of element in β dimension

dg = width of element in γ direction

$R1_s$ = R1 value of surface to which Nth element belongs

$R2_s$ = R2 value of surface to which Nth element belongs

$R3_s$ = R3 value of surface to which Nth element belongs

φ_s = φ value of surface to which Nth element belongs

ψ_s = ψ value of surface to which Nth element belongs

ω_s = ω value of surface to which Nth element belongs

α_s = α value of surface to which Nth element belongs

A.2.3 View Factor Computation

The view factors between each pair of nodes are found by a finite difference approximation. (Actually, the product of area times view factor, FA , is computed.)

Let $\underline{P}_1$ = position vector of the i^{th} element on Node 1 (POS vector)

$\underline{P}_2$ = position vector of the j^{th} element on Node 2 (POS vector)

$\underline{P}_{12} = \underline{P}_2 - \underline{P}_1$

$\underline{A}_1$ = area vector of the i^{th} element on Node 1 (ARA vector)

$\underline{A}_2$ = area vector of the j^{th} element on Node 2 (ARA vector)

Then

$$(FA)_{1-2} = \sum_{\substack{\text{elements} \\ \text{of Node 1}}} \sum_{\substack{\text{elements} \\ \text{of Node 2}}} X\,Y\,Z \, \frac{(\underline{A}_1 \cdot \underline{P}_{12})(-\underline{A}_2 \cdot \underline{P}_{12})}{\pi(\underline{P}_{12} \cdot \underline{P}_{12})^2} \qquad (1)$$

where

$X = 1$ if $\underline{A}_1 \cdot \underline{P}_{12} > 0$
  0 if $\underline{A}_1 \cdot \underline{P}_{12} \le 0$

$Y = 1$ if $\underline{A}_2 \cdot \underline{P}_{12} < 0$
  0 if $\underline{A}_2 \cdot \underline{P}_{12} \ge 0$

$Z = 1$ if the two elements "see" each other clearly
  0 if a third surface intervenes between the two elements

<u>Shading check (Z = 0 or 1).</u> Shading check routines have been worked out for the generalized heat flux program where the third, possibly intervening, surface is either a rectangle, disk, or trapezoid.

In addition to the definition above let:

$\underline{P}_l$ = position vector of L^{th} element in the third surface

$\underline{A}_l$ = area vector of L^{th} element in the third surface

$\underline{P}_j$ = position vector of J^{th} element in Node 2

$\underline{P}_i$ = position vector of I^{th} element in Node 1

$\underline{P}_p$ = position vector of intersection point of third plane surface and of the line between the I^{th} and J^{th} element

Combining the equation of the line

$$\underline{P}_p = \underline{P}_j + r(\underline{P}_i - \underline{P}_j)$$

and the equation of the plane

$$\underline{A}_l \cdot (\underline{P}_p - \underline{P}_l) = 0$$

at the point of intersection, P_p gives the parameter r

$$r = \frac{\underline{A}_l \cdot (\underline{P}_l - \underline{P}_j)}{\underline{A}_l \cdot (\underline{P}_i - \underline{P}_j)}$$

with the restrictions that, if $\underline{A}_l \cdot (\underline{P}_l - \underline{P}_j) = 0$ or if $\underline{A}_l \cdot (\underline{P}_i - \underline{P}_j) = 0$, no intersection point is possible, $(Z = 0)$ and that the intersection point be between the I^{th} and J^{th} element, that is, $A > 0$ so that $K = 1$, where

$$a = \frac{\underline{P}_p - \underline{P}_i}{\underline{P}_j - \underline{P}_p}$$

If the point $\underline{P}_p$ lies within the boundary of the third surface, then elements I and J cannot "see" each other $(Z = 0)$. If it lies outside this boundary, then the elements can "see" each other $(Z = 1)$.

Table A-1

TESTING FOR LOCATION OF $\underline{P}_p$

Geometric Surface	Step 1	Step 2
Rectangle	Test PY vs. β_{min} and β_{max} If PY $< \beta_{min}$ or PY $> \beta_{max}$, K = 1 If $\beta_{min} \leq$ PY $\leq \beta_{max}$, do step 2	Test PX vs. γ_{min} and γ_{max} If PX $< \gamma_{min}$ or PX $> \gamma_{max}$, K = 1 If $\gamma_{min} \leq$ PX $\leq \gamma_{max}$, K = 0
Disk	Test R $= \sqrt{PX^2 + PY^2}$ vs. β_{max} and β_{min} If R $< \beta_{min}$ or R $> \beta_{max}$, K = 1 If $\beta_{min} \leq$ R $\leq \beta_{max}$, do step 2	Test GR $= \cos^{-1}$(PY/R) vs. γ_{min} and γ_{max} If GR $< \gamma_{min}$ or GR $> \gamma_{max}$, K = 1 If $\gamma_{min} \leq$ GR $\leq \gamma_{min}$, K = 0
Trapezoid	Test PY vs. β_{min} and β_{max} If PY $< \beta_{min}$ or PY $> \beta_{max}$, K = 1 If $\beta_{min} \leq$ PY $\leq \beta_{max}$, do step 2	Test R $= \sqrt{PX^2 + PY^2}$ vs. γ_{min} and γ_{max} If R $< \gamma_{min}$ or R $> \gamma_{max}$, K = 1 If $\gamma_{min} \leq$ R $\leq \gamma_{max}$, K = 0

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The location of $\underline{P}_p$ is tested as shown in Table A-1 for the three geometric surfaces, where $\underline{P}_p = PX + PY + PZ$ in the (3′, 2′, 1′) system.

A.2.4 Planetary Emissive Power

The planet surface temperature is assumed to have a cosine distribution on the light side from T_{ss} at the subsolar point to T_{DS} at the terminator, and to be uniform at T_{DS} on the dark side.

The visible portion of the planet surface is divided into 36 nodes. The mean emissive power of each node is

$$W_I = \sigma \left[T_{DS} + \cos\theta_I (T_{ss} - T_{DS}) \right]^4$$

where

σ = Stephan-Boltzmann constant

W_I = emissive power of I^{th} planet node

θ_I = angle between surface normal of I^{th} planet node and planet sun line

The angle θ_I varies over the node, so a mean value of cos θ_I, as calculated in the OMEGA subroutine is used, as follows:

$$\cos\theta_I = \left[\sum_{\substack{\text{elements}\\ \text{of Node I}}} X \underline{A}_N \cdot (\underline{P}_S - \underline{P}_N) \right] \Big/ A_I R_{PS}$$

where

$\underline{A}_N$ = area vector of the N^{th} element of Node I

$\underline{P}_N$ = position of vector of N^{th} element of Node I

$\underline{P}_S$ = position vector of sun

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A_I = area of Node I
R_{PS} = distance from planet to sun
X = 1 if $\underline{A}_{N'} (\underline{P}_S - \underline{P}_N) > 0$
0 if $\underline{A}_{N'} (\underline{P}_S - \underline{P}_N) \leq 0$

An effective planetary emissive power, W_P, is now defined as

$$W_P = \sum_{\substack{\text{Planet} \\ \text{Node}}} A_I \times W_I / A_P \tag{5}$$

where A_P equals the total planet surface area.

A.2.5 Incident Fluxes

The direct incident fluxes may now be formed.

The incident solar flux to radiator surface J is

$$q_{SI(J)} = \left(\frac{FA_{S-J}}{A_J} \right) W_S \tag{6}$$

The incident albedo flux to radiator surface J is

$$q_{RI(J)} = \sum_{\substack{\text{Planet} \\ \text{Nodes}}} \left(\frac{FA_{S-I}}{A_I} \right) \left(\frac{FA_{I-J}}{A_J} \right) \rho_I W_S \tag{7}$$

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The incident planetary flux to radiator surface J is

$$q_{PI(J)} = \sum_{\substack{\text{Planet}\\\text{Nodes}}} \left(\frac{FA_{I-J}}{A_J}\right) W_I \tag{8}$$

where

A_J = area of J^{th} radiator surface
A_I = area of I^{th} planet node
FA_{S-J} = area × view factor, sun to J^{th} radiator surface
FA_{S-I} = area × view factor, sun to I^{th} planet node
FA_{I-J} = area × view factor, I^{th} planet node to J^{th} radiator surface
W_S = emissive power of sun = $\sigma[T_{sun}]^4$
W_I = emissive power of I^{th} planet node
ρ_I = planet albedo

A.2.6 Radiation Constants

Effective planetary and albedo view factors. The planetary flux incident of the J^{th} radiator surface is computed above to be

$$q_{PI(J)} = \sum_{\substack{\text{Planet}\\\text{Nodes}}} \left(\frac{FA_{I-J}}{A_J}\right) W_I$$

This is equivalent mathematically to the incident flux from a body of emissive power W_P – as defined in Eq. (5) above – radiating to the surface with a view factor of

$$FA_{P-J} = \frac{q_{PI(J)}}{W_P} \tag{9}$$

Similarly, the albedo flux can be expressed as the flux from a body of emissive power W_S (solar emissive power) radiated toward the surface with a view factor of

$$FA_{R-J} = \frac{q_{RI(J)}}{W_S} \tag{10}$$

Thus, the fluxes on the radiator surfaces can be separated into three independent components:

- Solar: the flux from a body of emissive power W_S radiating to each surface with a view factor FA_{S-J}
- Albedo: the flux from a body of emissive power W_S radiating to each surface with a view factor FA_{R-J} (the fact that this flux originated in the sun is irrelevant mathematically; we are concerned only with what happens after it leaves the planet)
- Planetary: the flux from a body of emissive power W_P radiating to each surface with a view factor FA_{P-J} (the fact that the temperature of the planet is nonuniform is irrelevant; we are concerned only with the total amount of flux received from the planet)

Radiation constant equations. It is convenient to start with Hottel's equations as presented in McAdams, Heat Transmission, 3rd ed., Eqs. 4 through 25. These equations may be rewritten in more general form as

$$\left(A_I F_{II} - \frac{A_I}{\rho_I}\right)({}_J R_I) + \sum_{K=1}^{N(K \neq I)} A_K F_{KI}({}_J R_K) = -\epsilon_J A_J F_{JI} \tag{11}$$

But, from Eq. 4-23a of the same reference,

$$A_I({}_J R_I) = \frac{\rho_I}{\epsilon_I} G_{JI} \tag{12}$$

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where G_{JI} is the radiation constant between J and I. Therefore,

$$\frac{1-\rho_I F_{II}}{\epsilon_I} G_{JI} - \sum_{K=1}^{N(K \neq I)} \frac{\rho_K F_{KI}}{\epsilon_K} G_{JK} = \epsilon_J A_J F_{JI} \quad ; \quad i = 1, N \quad ; \quad j = 1, N \tag{13}$$

This equation may be written in matrix form as

$$\begin{bmatrix} \frac{1-\rho_1 F_{11}}{\epsilon_1} & -\frac{\rho_2 F_{21}}{\epsilon_2} & \cdots & -\frac{\rho_N F_{N1}}{\epsilon_N} \\ -\frac{\rho_1 F_{12}}{\epsilon_1} & \frac{1-\rho_2 F_{22}}{\epsilon_2} & \cdots & -\frac{\rho_N F_{N2}}{\epsilon_N} \\ & \cdots & & \\ -\frac{\rho_1 F_{1N}}{\epsilon_1} & -\frac{\rho_2 F_{2N}}{\epsilon_N} & \cdots & \frac{1-\rho_N F_{NN}}{\epsilon_N} \end{bmatrix} \times \begin{bmatrix} G_{11} & G_{21} & \cdots & G_{N1} \\ G_{12} & G_{22} & \cdots & G_{N2} \\ & \cdots & & \\ G_{1N} & G_{2N} & \cdots & G_{NN} \end{bmatrix}$$

$$= \begin{bmatrix} \epsilon_1 A_1 F_{11} & \epsilon_2 A_2 F_{21} & \cdots & \epsilon_N A_N F_{N1} \\ \epsilon_1 A_1 F_{12} & \epsilon_2 A_2 F_{22} & \cdots & \epsilon_N A_N F_{N2} \\ & & \cdots & \\ \epsilon_1 A_1 F_{1N} & \epsilon_2 A_2 F_{2N} & \cdots & \epsilon_N A_N F_{NN} \end{bmatrix} \tag{14}$$

This equation may be solved for the G_{IJ}'s by matrix inversion and multiplication. The quantity G_{IJ} in the radiation constant between Node I and Node J, represents the portion of the flux emitted from Node I that is absorbed by Node J, including all reflections from other surfaces. Because of the symmetry of the FA's, G_{IJ} is also the portion of the flux from Node J that is absorbed by Node I.

Applying this general equation to the three types of flux, we have for M radiator surfaces and 1 external surface the following matrices for solar, albedo, and planetary fluxes:

- Solar (α_J = solar absorptivity of surface J)

$$\begin{bmatrix} \frac{1+(\alpha_1-1)F_{11}}{\alpha_1} & \cdots & \frac{\alpha_M-1}{\alpha_M}F_{M1} & \frac{\alpha_S-1}{\alpha_S}F_{S1} \\ & & \cdots & \\ \frac{\alpha_1-1}{\alpha_1}F_{1M} & \cdots & \frac{1+(\alpha_M-1)F_{MM}}{\alpha_M} & \frac{\alpha_S-1}{\alpha_S}F_{SM} \\ \frac{\alpha_1-1}{\alpha_1}F_{1S} & \cdots & \frac{\alpha_M-1}{\alpha_M}F_{MS} & \frac{1+(\alpha_S-1)F_{SS}}{\alpha_S} \end{bmatrix}$$

$$\times \begin{bmatrix} G_{11} & \cdots & G_{M1} & G_{S1} \\ & \cdots & & \\ G_{1M} & \cdots & G_{MM} & G_{SM} \\ G_{1S} & \cdots & G_{MS} & G_{SS} \end{bmatrix} = \begin{bmatrix} \alpha_1A_1F_{11} & \cdots & \alpha_MA_MF_{M1} & \alpha_SA_SF_{S1} \\ & & \cdots & \\ \alpha_1A_1F_{1M} & \cdots & \alpha_MA_MF_{MM} & \alpha_SA_SF_{SM} \\ \alpha_1A_1F_{1S} & \cdots & \alpha_MA_MF_{MS} & \alpha_SA_SF_{SS} \end{bmatrix} \qquad (15a)$$

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- Albedo (β_J = Albedo absorptivity of surface J)

$$
\begin{bmatrix}
\frac{1+(\beta_1-1)F_{11}}{\beta_1} & \cdots & \frac{\beta_M-1}{\beta_M}F_{M1} & \frac{\beta_R-1}{\beta_R}F_{R1} \\
 & & \cdots & \\
\frac{(\beta_1-1)}{\beta_1}F_{1M} & \cdots & \frac{1+(\beta_M-1)F_{MM}}{\beta_M} & \frac{\beta_R-1}{\beta_R}F_{RM} \\
\frac{\beta_1-1}{\beta_1}F_{1R} & \cdots & \frac{\beta_M-1}{\beta_M}F_{MR} & \frac{1+(\beta_R-1)F_{RR}}{\beta_2}
\end{bmatrix}
$$

$$
\times \begin{bmatrix}
G_{11} & \cdots & G_{M1} & G_{R1} \\
 & \cdots & & \\
G_{1M} & \cdots & G_{MM} & G_{RM} \\
G_{1R} & \cdots & G_{MR} & G_{RR}
\end{bmatrix}
=
\begin{bmatrix}
\beta_1 A_1 F_{11} & \cdots & \beta_M A_M F_{M1} & \beta_R A_R F_{R1} \\
 & \cdots & & \\
\beta_1 A_1 F_{1M} & \cdots & \beta_M A_M F_{MM} & \beta_R A_R F_{RM} \\
\beta_1 A_1 F_{1R} & \cdots & \beta_M A_M F_{MR} & \beta_R A_R F_{RR}
\end{bmatrix}
\qquad (15b)
$$

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- Planetary: (ϵ_J = planetary absorptivity of surface J)

$$\begin{bmatrix} \frac{1+(\epsilon_1-1)F_{11}}{\epsilon_1} & \cdots & \frac{\epsilon_M-1}{\epsilon_M}F_{M1} & \frac{\epsilon_P-1}{\epsilon_P}F_{P1} \\ & & \cdots & \\ \frac{\epsilon_1-1}{\epsilon_1}F_{1M} & \cdots & \frac{1+(\epsilon_M-1)F_{MM}}{\epsilon_M} & \frac{\epsilon_P-1}{\epsilon_P}F_{PM} \\ \frac{\epsilon_1-1}{\epsilon_1}F_{1P} & \cdots & \frac{\epsilon_M-1}{\epsilon_M}F_{MP} & \frac{1+(\epsilon_P-1)F_{PP}}{\epsilon_P} \end{bmatrix}$$

$$\times \begin{bmatrix} G_{11} & \cdots & G_{M1} & G_{P1} \\ & & \cdots & \\ G_{1M} & \cdots & G_{MM} & G_{PM} \\ G_{1P} & \cdots & G_{MP} & G_{PP} \end{bmatrix} = \begin{bmatrix} \epsilon_1A_1F_{11} & \cdots & \epsilon_MA_MF_{M1} & \epsilon_PA_PF_{P1} \\ & & \cdots & \\ \epsilon_1A_1F_{1M} & \cdots & \epsilon_MA_MF_{MM} & \epsilon_PA_PF_{PM} \\ \epsilon_1A_1F_{1P} & \cdots & \epsilon_MA_MF_{MP} & \epsilon_PA_PF_{PP} \end{bmatrix} \tag{15c}$$

Combination of solar and albedo equations. As pointed out above, we can mathematically treat the solar and albedo fluxes as arising from two unrelated independent sources. If two further assumptions are made, it will be possible to combine the solar and albedo equations into a single equation. These two assumptions are:

- The absorptivity of each surface is the same for solar and albedo radiation; i.e., $\beta_J = \alpha_J$ for all surfaces.

- The presence of the satellite has no effect on the planet and sun. In particular, it is assumed that the solar flux reflected from the satellite onto the planet and the albedo flux reflected from the satellite onto the sun are both negligible. With this assumption, the assumption that the planet and sun can be treated as independent sources still holds.

The resulting combined equation is

$$\begin{bmatrix} \dfrac{1+(\alpha_1-1)F_{11}}{\alpha_1} & \cdots & \dfrac{\alpha_M-1}{\alpha_M}F_{M1} & \dfrac{\alpha_R-1}{\alpha_R}F_{R1} & \dfrac{\alpha_S-1}{\alpha_S}F_{S1} \\ \dfrac{\alpha_1-1}{\alpha_1}F_{1M} & \cdots & \dfrac{1+(\alpha_M-1)F_{MM}}{\alpha_M} & \dfrac{\alpha_R-1}{\alpha_R}F_{RM} & \dfrac{\alpha_S-1}{\alpha_S}F_{SM} \\ \dfrac{\alpha_1-1}{\alpha_1}F_{1R} & \cdots & \dfrac{\alpha_M-1}{\alpha_M}F_{MR} & \dfrac{1+(\alpha_R-1)F_{RR}}{\alpha_R} & 0 \\ \dfrac{\alpha_1-1}{\alpha_1}F_{1S} & \cdots & \dfrac{\alpha_M-1}{\alpha_M}F_{MS} & 0 & \dfrac{1+(\alpha_S-1)F_{SS}}{\alpha_S} \end{bmatrix}$$

$$\times \begin{bmatrix} G_{11} & \cdots & G_{M1} & G_{R1} & G_{S1} \\ & & \cdots & & \\ G_{1M} & \cdots & G_{MM} & G_{RM} & G_{SM} \\ G_{1R} & \cdots & G_{MR} & G_{RR} & G_{SR} \\ G_{1S} & \cdots & G_{MS} & G_{RS} & G_{SS} \end{bmatrix} = \begin{bmatrix} \alpha_1A_1F_{11} & \cdots & \alpha_MA_MF_{M1} & \alpha_RA_RF_{R1} & \alpha_SA_SF_{S1} \\ & & \cdots & & \\ \alpha_1A_1F_{1M} & \cdots & \alpha_MA_MF_{RM} & \alpha_RA_RF_{RM} & \alpha_SA_SF_{SM} \\ \alpha_1A_1F_{1R} & \cdots & \alpha_MA_MF_{MR} & \alpha_RA_RF_{RR} & 0 \\ \alpha_1A_1F_{1S} & \cdots & \alpha_MA_MF_{MS} & 0 & \alpha_SA_SF_{SS} \end{bmatrix} \tag{16}$$

NOTE: The solar and albedo fluxes were combined for Phase I of the Heat Flux Study (see Section 4, Parametric Study) but were not combined in the Generalized Heat Flux Computer Program.

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The radiation constant between the sun and radiator surface J (G_{SJ}) includes the flux coming directly from the sun to the satellite plus the negligibly small amount that reflects from the satellite to the planet and then back to the satellite. It does not include any flux reflected from the planet because in this mathematical model we have set the view factor from the sun to the planet (F_{SR}) equal to zero. Similarly, the radiation constant between the planet and radiator surface J (G_{RJ}) includes only the albedo flux from the planet to the satellite arising from the F_{RK} terms plus a negligibly small amount reflected from the satellite to the sun and then back to the satellite.

A.2.7 Absorbed Fluxes

The equations for fluxes absorbed by the radiator surfaces are as follows:

- Solar flux absorbed by surface J

$$q_{SA(J)} = \frac{G_{SJ}}{A_J} \times W_S$$

- Albedo flux absorbed by surface J

$$q_{RA(J)} = \frac{G_{RJ}}{A_J} \times W_S$$

- Planetary flux absorbed by surface J

$$q_{PA(J)} = \frac{G_{PJ}}{A_J} \times W_J$$

NOTE: The above absorbed fluxes are on a per unit basis upon which the Phase I study was conducted. However, the Generalized Heat Flux Computer Program calculates these for the entire surface J, so that the following equations apply:

- $q_{SA(J)} = G_{SJ} \times W_S$
- $q_{RA(J)} = G_{RJ} \times W_S$
- $q_{PA(J)} = G_{PJ} \times W_S$

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A.3 DEFINITION OF SYMBOLS STORED IN COMMON LOCATION OF COMPUTER PROGRAM

The values represented by these symbols are stored in COMMON for use by the Main Program and the subroutines.

Symbol	Code	Explanation
DATA (J)		Surface identification for the sun, the planet, and each of the space vehicle geometric surface configurations
	J = 1	The sun
	J = 2	The planet
	J = 3 to N	The vehicle surfaces (N maximum is defined under K = 5)
DATA (K)		Location of parameters that describe each surface (see Figs. A-10 through A-12)
	K = 1	The surface type (±1, ±2, ±3, ±6), ILK
	K = 2	Number of Δ elements in the beta direction, $N\beta$
	K = 3	Number of Δ elements in the gamma direction, NG
	K = 4	Number of heat flux tables or the number of view factor nodes in the beta direction, $NV\beta$
	K = 5	Number of heat flux tables or the number of view factor nodes in the gamma direction, NVG

NOTE

Number of heat flux tables output or the number of view factor nodes for each surface type, DATA (J,1), is $(NVG)(NV\beta) = T_j$, where the total number of heat flux tables or view factor nodes would be $T = \sum_{J=3}^{J=N} T_j$, and where the limits on T are $1 \leq T \leq 20$

Symbol	Code	Explanation
	K = 6	α, the geometric constant
	K = 7	Beta minimum, β_{min}

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Symbol	Code	Explanation
	K = 8	Gamma minimum, γ_{min}
	K = 9	Beta maximum, β_{max}
	K = 10	Gamma maximum, γ_{max}
	K = 11	R(1), translation in the 1 direction
	K = 12	R(2), translation in the 2 direction
	K = 13	R(3), translation in the 3 direction
	K = 14	ϕ, yaw angle
	K = 15	ψ, pitch angle
	K = 16	ω, roll angle
POS (J,K)		Position vector of the center of each element from the central coordinate system (includes the sun and planet as well as all the vehicle surfaces)
	J	Location of the identification number of the element
	K = 1	Z component of the position vector
	K = 2	Y component of the position vector
	K = 3	X component of the position vector
ARA (J,K)		Area vector of J^{th} element directed as defined by the sign of DATA (J,1)
	J	Location of the identification number of the element
	K = 1	Z component of the area vector
	K = 2	Y component of the area vector
	K = 3	X component of the area vector
FA (J,K)		View factor from node J to node K times the area of node J [according to the reciprocity theorem, FA (J, K) = FA (K, J)]
	J = 1	Sun node
	J = 2 to 37	Planet nodes
	J = 38 to N	Vehicle nodes, where N maximum is 57

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Symbol	Code	Explanation
AREA (J)		Area of the view factor nodes as described in FA (J, K)
	J = 1	Sun node area
	J = 2 to 37	Planet node areas
	J = 38 to N	Vehicle node areas
COST (J)		Mean cosine of the angle between each planet area normal and the planet-sun line
	J = 1	Zero
AS (J)		Solar absorptivity of each surface
	J = 2	Absorptivity of the planet (α_s = 1 - albedo)
	J = 3 to 22	Absorptivity of each set of cards that describe the vehicle surface
AA (J)		Albedo absorptivity of each surface
	J = 3 to 22	Absorptivities of the vehicle surface
E (J)		Planetshine absorptivity of each surface and the emissivities of the vehicle surfaces
	J = 3 to 22	Values for the vehicle surfaces
P (I, J, K)		Matrix for the rotation of the I^{th} surface configuration to the central coordinate system by means of ϕ, ψ, and ω
	I = 1	Sun rotation
	I = 2	Planet rotation
	I = 3 to 22	Vehicle surfaces rotated

NOTE

This matrix is also used for the rotation of all element area and position vectors

	J and K	A 3 × 3 matrix, I = 22

Symbol	Code	Explanation
NS		Number of surfaces that are input to describe a geometric configuration plus 1 for the sun and plus 1 for the planet
SHD		A flag to determine if the shading check routine is to be used
	SHD = +1	Shading routine to be used
	SHD = 0 or -1	Shading routine not to be used
NITE		A flag to determine if the vehicle is in the planet shadow
	NITE = +1	Vehicle in the shadow
	NITE = 0 or -1	Vehicle in the sunlight
IZ		A flag to determine if the present calculation is the first one done by the machine
	IZ = 1	First calculation done by the machine
	IZ = 0	Second or later calculation done by the machine
IK		A flag to indicate if vehicle is a planet-oriented satellite in a circular orbit
	IK = +1	Not a planet-oriented satellite in a circular orbit
	IK = 0	A planet-oriented satellite in a circular orbit
A (J)		Position vector as described in the prime coordinate system for each $NG \times N\beta$ element
NV		Number of view factor nodes used in the program; can vary from NV = 38 (1 vehicle surface node) to NV = 57 (20 vehicle surface nodes)
NTN (J)		Total number of elements ($N\beta \times NG$) including those of the J^{th} view factor node
	J = 1	Number of $NG \times N\beta$ for the sun = 1

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Symbol	Code	Explanation
	J = 37	Number of NG × Nβ for the sun and planet
	J = 38	Number of NG × Nβ for the sun, the planet, and the first vehicle surface
RAD		Radius vector magnitude from the planet center to the vehicle at each point in orbit
PI		Pi (π = 3.1415927)
DCR		$\pi/180$
RPLAN		Radius of the planet
IN (J)		A flag to indicate the I^{th} orbit point when the satellite enters the planet shadow (J = 1) and the I^{th} point when the satellite leaves the planet shadow (J = 2)
TIME (J)		Orbit time that heat fluxes correspond to J = 1
	J = 1	First point in orbit
FXS (J, K)		Direct solar incident flux per unit area on surface J at orbit time K (plus direct albedo flux per unit area if the two fluxes are to be combined)
FXA (J, K)		Direct albedo incident flux per unit area on surface J at time K
FXP (J, K)		Direct planetshine incident flux per unit area on surface J at time K
KLUXS (J, K)		Total absorbed solar flux for surface area J at time K (plus total absorbed albedo flux for surface area J at time K if the two fluxes are to be combined)
FLUXA (J, K)		Total absorbed albedo flux for surface area J at time K

Symbol	Code	Explanation
FLUXP (J, K)		Total absorbed planetshine for surface area J at time K
B (J, K)		The matrix that is to be inverted to obtain the radiation constant matrix from the equation $[D] = [B]^{-1} C$
WRIT (J, K)		The alphanumerical storage of the Hollerith written on the J^{th} set of cards to identify the J surface of the table output
ECC		Eccentricity of the vehicle orbit
PERIOD		Orbit period
NPO		Number of points to be calculated in orbit (plus four if the vehicle goes into and out of the planet's shadow)
NTABLE		A flag to determine if the Heat Flux tables are to be combined, . . . , i.e., NTABLE = 1 then Solar and Albedo Heat Fluxes will be combined NTABLE = 2 then the fluxes will be output as solar, albedo, and planetshine
SBC		Stephan-Boltzman constant
TSUN		Temperature of the sun
TSS		Temperature of the planet surface at the subsolar point
TDS		Temperature of the planet surface on the dark side
RADK (J, K)		The radiation constant between the satellite surfaces and also between the satellite surfaces and space (these values are $\sigma F_{J,K} A_J$)
	K = 21	The outer space node (surfaces are numbered in the order that they are input to the program)

Symbol	Code	Explanation
THE		The angle between the projection of the solar vector on the orbit plane and the periapsis of the orbit plane in the direction of satellite travel
BETA		The angle between the solar vector and its perpendicular projection on the orbit plane
KAD		A flag to indicate the type of orbit
	KAD = +1	Heat rates for a partial orbit are to be calculated
	KAD = -1	Heat rates for a periodic orbit are to be calculated
DSUN		Distance from the planet center to the sun

A.4 FLOW DESCRIPTION OF THE MAIN PROGRAM AND SUBROUTINES OF THE COMPUTER PROGRAM

This part of Appendix A explains the calculations made by the computer as it proceeds through the program. The statement numbers refer to the Main Program or subroutine under which they appear. Appendix E contains complete listings of all programs.

A.4.1 Main Program

The Main Program reads in the input data, writes out the input data, and stores the data to be used for a particular orbital case. It increments the satellite around the prescribed orbit it has determined and calculates the orbit time corresponding to each point in the orbit plane. The Main Program calls subroutines to calculate the shadow points of the satellite orbit, the geometric view factors and the heat fluxes at each point in orbit, and the written output of the heat flux tables.

Statement Number	Activity
15	Reads in the first card of every input block.
20 – 30	Completes the reading in of Block 1 and writes out Block 1. The length measurement of the input variables are converted and stored. The sun and planet data matrix variables are assigned.
30 – 40	Completes the reading of Block 2 and writes out Block 2. The length measurements of the input variables are converted and stored. The β and α_s angles are calculated for the orbit.
40 – 44	Block 3 is written out. The matrix to rotate the orbit plane coordinate system (X'', Y'', Z'') to the central coordinate system (X, Y, Z) is assigned.
44 – 49	Completes the reading in of Block 4 and writes out Block 4. The data matrix for each satellite surface is assigned as well as the Hollerith matrix for each surface.
49 – 51	Block 5 is written out.
51 – 52	The orbit period and eccentricity are calculated.
52 – 57	The Δ geocentric degrees that the satellite moves between points is calculated. A flag is set for full or partial orbit heat fluxes.
57 – 71	The orbit time from periapsis to the initial point in orbit, θ_I, is calculated.
72	The distance from the planet center to the satellite for a circular orbit is assigned.
80 – 85	A flag for the initial theta angle, θ_I, and the corresponding correct sign for the orbit time from periapsis to the initial point in orbit.

Statement Number	Activity
86	SHADOW subroutine is called in which the geocentric angles from the projection of the solar vector on the orbit plane to the shadow points is calculated.
86 – 116	Determines the initial point in orbit at θ_I, determines if the satellite is in or out of the sun at this angle, and sets the corresponding flags.
116 – 120	Zero initial values before the calculation of each point in orbit.
120 – 270	A loop which is executed for each point in orbit.
280 – 310	The particular orbit-point fluxes at the shadow points of the orbit plane are calculated for which special flags and calculations are made. Then the program transfers back to complete the 120 – 270 loop.
120 – 146	Determines if the $\Delta\theta$ increment has moved the satellite from the sunlight to the planets' shadow or vice versa. If so, the program transfers to 280; if not, the program continues with statement 149.
149	Determines if all the points have been computed.
150 – 156	Assigns the initial orbit time.
157 – 158	Determines if all points have been computed, even for the partial orbit.
160 – 183	Orbit time from periapsis to the i^{th} point in the orbit is calculated.
183 – 210	Orbit time from the initial point, $i = 1$, to the i^{th} point is calculated.

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Statement Number	Activity
220 – 230	Calculations are made for the i^{th} position of the sun and planet relative to the central coordinate system for a planet-oriented satellite.
230 – 240	Calculations are made for the i^{th} position of the sun and planet relative to the central coordinate system for a sun-oriented satellite.
240 – 270	The data matrix for the sun and planet is completed from the calculations made in statement numbers 220 – 230 or 230 – 240 for the i^{th} point.
270	The VIEW and FLUX subroutines are called to calculate the view factors and heat fluxes for the i^{th} point in orbit.
402	OUTPUT subroutine is called to write out the heat fluxes.

A.4.2 SHADOW Subroutine

This subroutine calculates the geocentric angles from the projection of the solar vector on the orbit plane to the intersection points of the planet's shadow and the satellite's path. These angles are approximated by finite difference calculations as the radius vector (center of the planet to the satellite) is incremented along the satellite path. The present accuracy of the resulting angles is ≥ 0.01 deg. This part of Appendix A contains the equations and assumptions of this subroutine. In this subroutine, $\theta \equiv \alpha_s$ + theta to intersection point.

Statement Number	Activity
1	Starts a "Do" loop in which the size of the $\Delta\theta$ is determined.
1 – 2	A "Do" loop that divides the $\Delta\theta$ by 10 and adds this angle to θ in the correct direction toward the intersection point.

120

Statement Number	Activity
4 – 6	Determines the correct direction that $\Delta\theta$ is moved from θ = 270 deg or θ = 90 deg.
7	Constants assigned to the θ angles if no intersection occurs; i.e., 100 percent of the satellite orbit is in the sun.

A.4.3 VIEW Subroutine

This subroutine takes the geometric description of the satellite surfaces and the relative position of the sun and the planet for this i^{th} position in orbit, and subdivides these surfaces in this i^{th} position into elements. The number of elements that the planet is subdivided into is also calculated.

Statement Number	Activity
1 – 4	Flags set by the Main Program are checked to determine how many calculations need to be repeated.
5 – 20	The number of elements that each of the planet's 36 nodes is subdivided into is determined in the two "Do" loops. When the calculated view factor error to the planet is less than the desired error input by the program user, a transfer is made from the "Do" loop.
20 – 50	A "Do" loop which assigns node numbers and element numbers to each defined geometric surface (includes the sun and the planet surfaces as well as the satellite surfaces).

NOTE

This loop is executed in the following sequence: The rotation matrix from the X, Y, Z system to the X′, Y′, Z′ for each J^{th} surface is assigned.

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Statement Number	Activity
22 – 35	The nodes and elements in the β and γ directions are assigned 1 if they were ≤ 0 and then are restored in the data matrix.
35 – 50	Divides the J^{th} surface into nodes and elements. VECTOR subroutine is called for each element of each node in the J^{th} surface.
54 – 70	Diagnostics for too many elements or too many nodes.
80	Subroutine Omega is called.

A.4.4 VECTOR Subroutine

This subroutine calculates the area vector of each element and the position vector (from X, Y, Z origin to center of element) of each element.

Statement Number	Activity
21 – 22	The area and position vector for an element in a rectangular surface relative to the X′, Y′, Z′ system is calculated.
22 – 23	The area and position vector for an element in a disk surface relative to the X′, Y′, Z′ system is calculated.
23 – 26	Same as above, but for a triangular surface.
26 – 80	Same as above, but for a spherical surface.
80 – 90	The area vector is transformed from the X′, Y′, Z′ system to the X, Y, Z system and is stored.
100	The position vector is transformed from the X′, Y′, Z′ system to the X, Y, Z system and is stored.

A.4.5 OMEGA Subroutine

The FA matrix is calculated between each element and then added until the stored FA matrix becomes the FA matrix between nodes. Also, the cosine of the angle between the planet-sun line and each planet node is calculated and stored, COST (J).

Statement Number	Activity
2 – 8	Flags set in the Main Program are checked to eliminate duplicate calculations.
8 – 12	The node areas and FA node values to be calculated are set equal to zero.
12 – 100	A "Do" loop.
12 – 21	Calculates the area magnitude of the i^{th} element and sets flags.
21 – 99	A "Do" loop within the 12 – 100 "Do" loop.
21 – 30	Calculates the dot product between the spread vector (vector from i^{th} element to j^{th} element) and the i^{th} element, and the dot product between the j^{th} element and the spread vector.
32 – 33	The COST (J) is calculated for the sun element and the j^{th} planet node.
37 – 39	Flags are checked to determine if surface shading of the satellite surfaces is possible for the i^{th} and j^{th} elements.
44	SHADE subroutine is called.
95 – 99	The FA for the i^{th} and j^{th} elements are added if no shading takes place.
103 – 107	The average COST (J) of the planet node is calculated and the FA matrix is completed.

A.4.6 SHADE Subroutine

This subroutine determines if there is an intervening surface between the i^{th} and j^{th} element such that the centerlines between these elements would intersect this third surface.

Statement Number	Activity
5 – 10	Determination of which vehicle surface may be the intervening surface and the area vector, L , on this surface.
12 – 22	Calculation of direction number of the line between the i^{th} and j^{th} elements.
22 – 25	Does the j^{th} element lie in the plane of the possible intervening surface?
27 – 40	Are the line and the surface normal, L , perpendicular? The point of intersection in the X, Y, Z coordinate system is found and transformed into the X′, Y′, Z′ coordinate system of the possible intervening surface.
40 – 50	If the surface is a rectangle, does the point of intersection lie within the prescribed boundaries of this surface?
50 – 60	If the surface is a disk, does the point of intersection lie within the prescribed boundaries of this surface?
60 – 68	If the surface is a triangle, does the point of intersection lie within the prescribed boundaries of this surface?

A.4.7 FLUX Subroutine

This subroutine calculates the direct incident fluxes, the total absorbed fluxes, and the radiation constants for the satellite surfaces.

Statement Number	Activity
2 – 6	The α_s, α_A, and ϵ are assigned to all nodes of a given surface, and the emissive power of the sun is calculated for the initial point in orbit.
6 – 10	The mean emissive power of the I^{th} planet node is calculated
10 – 20	The direct incident solar, albedo, and planetshine flux is calculated for an entire node of the satellite.
24 – 35	The planetshine B and GS matrices are defined and assigned values. Then INVERT subroutine is called which inverts the B matrix.
35 – 45	The GS matrix and the inverted B matrix are multiplied and stored in the GS matrix.
45 – 46	The GP matrix is assigned the GS (1,I) matrix.
46 – 60	The RADK matrix is calculated which includes the radiation constant to space.
60 – 68	The albedo B and GS matrices are defined and assigned values. Then INVERT subroutine is called which inverts the B matrix.
68 – 75	The GS matrix and the inverted B matrix are multiplied and stored in the GS matrix.
77	The GA matrix is assigned the GS (1,I) matrix.
80 – 87	The solar B and GS matrices are defined and assigned values. The INVERT subroutine is called which inverts the B matrix.

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Statement Number	Activity
87 – 100	The GS matrix and the inverted B matrix are multiplied and stored in the GS matrix.
100	The table output is selected for the addition of the solar and albedo fluxes, 105 – 107, or their individual output, 110 – 112.
115 – 170	Assigns the specific heat fluxes as the satellite enters and leaves the planet shadow.

A.4.8 INVERT Subroutine

This subroutine inverts the B matrix assigned in FLUX subroutine. This is a non-orthogonal transformation so that the inverse matrix, B^{-1}, is not equal to the transpose matrix, B^{1}.

A.4.9 OUTPUT Subroutine

After all the heat fluxes are calculated for the points in the satellite orbit, this subroutine is executed.

Statement Number	Activity
51	The solar constant is calculated
54 – 64	The percent orbit time that the satellite is in the sun is calculated.
66 – 68	The variables are written out.
101 – 130	The total absorbed fluxes "Solar," "Albedo," and "Planet-shine" are written out.
130 – 155	The direct incident fluxes "Solar," "Albedo," and "Planet-shine" are written out.

Statement Number	Activity
160 – 176	The total absorbed fluxes "Solar," "Albedo," and "Planetshine" are punched out on cards if desired.
180 – 198	The direct incident fluxes "Solar," "Albedo," and "Planetshine" are punched out on cards if desired.
201 – 226	The total absorbed fluxes for "Solar," "Albedo," and "Planetshine" are written out.
226 – 255	The direct incident fluxes for "Solar," "Albedo," and "Planetshine" are written out.
260 – 280	The total absorbed fluxes for "Solar," "Albedo," and "Planetshine" are punched out on cards if desired.
283 – 299	The direct incident fluxes for "Solar," "Albedo," and "Planetshine" are punched out on cards if desired.

A.4.10 TRIG Package

The TRIG Package consists of four FAP coded subroutines, TAN, TRIG, ATAN, and AFUN for computing the trigonometric functions tangent, sine and cosine, and the inverse trigonometric functions arctangent, arcsine, and arccosine, for the angle in degrees.

All angles in the program are input and output in degrees. Thus the program is incompatible with the FORTRAN library subroutines SIN, COS, and ATAN without the use of conversion factors degrees to radians, and from radians back to degrees. Also, many calculations can be performed more simply in terms of tangent, arcsine, and arccosine functions which are not available in the FORTRAN library.

TAN Subroutine.

- Identification: TAN
- Purpose: Compute tangent (x) for x any single-precision floating-point argument in degrees, when TANF (X) is used in a floating-point expression.

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- Usage: TANF (X)

  Requires 236_8 locations
- Restrictions: None.
- Method: Based on two tables, TANT and INT, where

$$TANT(n) = \tan(n) \ , \ n = 0, 1, \ldots, 45, \text{ and}$$

$$INT(n) = \tan(n + 1/2) - \tan(n - 1/2) \ , \ n = 0, 1, \ldots, 45$$

The argument is divided into three parts; NQ, ND, and F, so that

Arg = 45 × NQ + ND + F

where,

NQ = integral part of (Arg/45), and indicates the octant in which Arg lies:

$0 + 180i \le Arg < 45 + 180i$; NQ = 0

$45 + 180i \le Arg < 90 + 180i$; NQ = 1

$90 + 180i \le Arg < 135 + 180i$; NQ = 2

$135 + 180i \le Arg < 180 + 180i$; NQ = 3

where i = 0, 1, 2,...

ND = integral part of (Arg mod 45) rounded to the nearest integer.

F = (Arg mod 45) - ND

The tangent of Arg is obtained from the TANT and INT tables:

NQ = 0: TANF (Arg) = TANT(ND) + F × INT(ND)

NQ = 1: TANF (Arg) = 1/[TANT(45 - ND) - F × INT(45 - ND)]

NQ = 2: TANF (Arg) = 1/[-TANT(ND) - F × INT(ND)]

NQ = 3: TANF (Arg) = -TANT(45 - ND) + F × INT(45 - ND)

<u>TRIG Subroutine.</u>

- Identification: TRIG
- Purpose: Compute sine (x) or cosine (x) for x any single precision floating point argument in degrees, where SINF(X) or COSF(X) is used in a floating-point expression.

- Usage: SINF(X), COSF(X)

  Requires 365_8 locations for both, coded as two entries to one routine.
- Restrictions: None
- Method: Based on two tables, SINT and INT, where

$$SINT(n) = \sin(n) \qquad , \; n = 0, 1, \ldots, 90$$

$$INT(n) = \sin(n + 1/2) - \sin(n - 1/2) \; , \; n = 0, 1, \ldots, 90$$

The argument is divided into three parts: NQ, ND, and F, so that Arg = $90 \times NQ + ND + F$,

where,

NQ = integral part of (Arg/90) and indicates the quadrant in which Arg lies:

$$0 + 360i \le Arg < 90 + 360i \quad : NQ = 0$$
$$90 + 360i \le Arg < 180 + 360i \quad : NQ = 1$$
$$180 + 360i \le Arg < 270 + 360i \quad : NQ = 2$$
$$270 + 360i \le Arg < 360 + 360i \quad : NQ = 4$$
$$-(0 + 360i) > Arg \ge -(90 + 360i) \quad : NQ = 2$$
$$-(90 + 360i) > Arg \ge -(180 + 360i) : NQ = 3$$
$$-(180 + 360i) > Arg \ge -(270 + 360i): NQ = 0$$
$$-(270 + 360i) > Arg \ge -(360 + 360i): NQ = 1$$

where $i = 0, 1, 2, \ldots$

ND = integral part of (Arg mod 90) rounded to the nearest integer

F = (Arg mod 90) - ND

The sine of Arg is obtained from the SINT and INT tables:

$$NQ = 0: \; SINF(Arg) = SINT(ND) + F \times INT(ND)$$
$$NQ = 1: \; SINF(Arg) = SINT(90 - ND) + F \times INT(90 - ND)$$
$$NQ = 2: \; SINF(Arg) = -SINT(ND) - F \times INT(ND)$$
$$NQ = 3: \; SINF(Arg) = -SINT(90 - ND) + F \times INT(90 - ND)$$

The cosine of Arg is evaluated as sine (Arg + 90).

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ATAN Subroutine

- Identification: ATAN
- Purpose: Compute arctangent (x) for x are single-precision, floating-point argument. The result is the principal value in degrees.
- Usage: ATANF (X)

  Requires 260_8 locations.
- Restrictions: None
- Method: Based on two tables, ATANT and INT, where

$$ATANT(n) = atan(n/100)_8 \qquad , n = 0, 1, \ldots, 100_8$$

$$INT(n) = atan[(n/100)_8 + 1/2] - atan[(n/100)_8 - 1/2] \quad , n = 0, 1, \ldots, 100_8$$

The argument is divided into two parts, ND and F, depending on the magnitude of Arg:

$|Arg| < 1$, ND = integral part of $(100/Arg)_8$ rounded to the nearest integer.

F = $(100/Arg)_8$ - ND

$|Arg| \geq 1$, ND = integral part of $(100/Arg)_8$ rounded to the nearest integer

F = $(100/Arg)_8$ - ND

The arctangent of Arg is obtained from the ATANT and INT tables:

$Arg < -1.$: ATANT (Arg) = ATANT(ND) + F × INT(ND) - 90.

$Arg = -1.$: ATANT (Arg) = -45.

$-1. < Arg < 0.$: ATANT (Arg) = -ATANT(ND) - F × INT(ND)

$0 \leq Arg < 1.$: ATANT (Arg) = ATANT(ND) + F × INT(ND)

$Arg = 1.$: ATANT (Arg) = 45.

$1. < Arg$: ATANT (Agr) = 90. - ATANT(ND) - F × INT(ND)

AFUN Subroutine

- Identification: AFUN
- Purpose: Compute arcsine (x) or arccosine (x) for x any single-precision floating-point argument. The result is the principal value $[-90 \leq ASIN(X) \leq 90., 0. \leq ACOSF(X) \leq 180]$ in degrees.

- Usage: ASINF(X), ACOSF(X)

  Requires 363_8 locations for both, coded as two entries to one routine.
- Restrictions: If Arg $\geq$ 1. , ASINF(Arg) = 90. , ACOSF (Arg) = 0.

  If Arg $\leq$ -1. , ASINF (Arg) = -90. , ACOSF (Arg) = 180.
- Method: Based on two tables, ASINT and INT, where

$$\text{ASINT}(n) = \text{asin}\,(n/200)_8 \qquad ; n = 0, 1, \ldots, 133_8$$

$$\text{Int}(n) = \text{asin}[(n/200)_8 + 1/2] - \text{asin}[(n/200)_8 - 1/2] \;; n = 0, 1, \ldots, 133_8$$

The argument is divided into two parts, ND and F, depending on the magnitude of Arg:

$|\text{Arg}| \leq 1/\sqrt{2}$, ND = integral part of $(200 * \text{Arg})_8$ rounded to the nearest integer

F = $(200 \times \text{Arg})_8$ - ND

$|\text{Arg}| > 1/\sqrt{2}$, ND = integral part of $\left[200 \times \sqrt{1 - (\text{Arg})^2}\right]_8$ rounded to the nearest integer

F = $\left[200 \times \sqrt{1 - (\text{Arg})^2}\right]_8$ - ND

The arcsine of Arg is obtained from the ASINT and INT tables:

$$
\begin{array}{rll}
\text{Arg} \leq -1. & : \text{ASINF (Arg)} & = -90. \\
-1. < \text{Arg} < -1/\sqrt{2} & : \text{ASINF (Arg)} & = \text{ASINT(ND)} + F \times \text{INT(ND)} - 90. \\
-1/\sqrt{2} \leq \text{Arg} < 0 & : \text{ASINF (Arg)} & = -\text{ASINT(ND)} - F \times \text{INT(ND)} \\
0 \leq \text{Arg} \leq 1/\sqrt{2} & : \text{ASINF (Arg)} & = \text{ASINT(ND)} + F \times \text{INT(ND)} \\
1/\sqrt{2} < \text{Arg} < 1 & : \text{ASINF (Arg)} & = 90. - \text{ASINT(ND)} - F \times \text{INT(ND)} \\
1 \leq \text{Arg} & : \text{ASINF (Arg)} & = 90.
\end{array}
$$

The arccosine of Arg is evaluated as 90. - arcsine (Arg).

Appendix B
PROGRAM INPUT/OUTPUT

B.1 DEFINITION OF INPUT VARIABLES

Physical variables that are input to the computer program are written out as shown in Fig. B-1. The physical input variables are divided into the following five blocks and are discussed in the order they appear.

- Planet data for Venus
- Satellite orbit
- Satellite orientation
- Satellite surfaces
- Output variables

Block 1 -- PLANET DATA FOR VENUS. The word VENUS in the title of block 1 is written out to identify the physical constants associated with the planet Venus. Any other planet in our solar system may be used as the planet about which heat fluxes are obtained on a satellite. There is some restriction as to the basic unit of length used by the computer for the "outer" five planets; this was explained in Section 3 of this report. The Earth's moon or another moon may also be treated as a planet in Block 1; the resulting orbit and heat fluxes are due to the moon and sun only. With the generalized input of Block 1, the heat fluxes about a planet in another solar system may be calculated with some restrictions, provided the physical constants are available.

The interpretation of the physical constants in Block 1 is as follows:

- The formulas used to determine the satellite's position around the planet are for the true elliptical orbit that considers the planet as a true homogeneous sphere or its equivalent, a point mass. Appendix A-1 contains these formulas. With this assumption, the planet's GRAVITATIONAL CONSTANT would be the "sea-level" value or the average planet surface value. The assumption of a true homogeneous sphere results in an average PLANET RADIUS.

- The PLANET DISTANCE TO SUN is tabulated in various references listed at the end of this appendix. This distance is often given in astronomical units that are tabulated for any day of a given year and must be converted to the desired distance units to be input to the computer program. The distance to the sun causes the following variation in the solar constant as the planet moves from perihelion to aphelion:

  Mars: 0.0642 -- 0.04425 Btu/sec-ft^2

  Earth: 0.1265 -- 0.1175 Btu/sec-ft^2

  Venus: 0.231 -- 0.240 Btu/sec-ft^2

- The SUN RADIUS and the SOLAR TEMPERATURE, in addition to the planet-to-sun distance, determines the solar constant at the planet. However, the exact sun radius and the mean effective solar temperature are difficult to obtain to any high degree of consistency from the reference material. It should be remembered when inputting these

```
THIS LINE, CORRESPONDING TO 1 CARD INPUT, IS FOR COMMENTS BY THE

   1  PLANET DATA FOR VENUS        0.32810E 04
        GRAVITATIONAL CONSTANT = 0.28900E 02          STEPHAN-BOLT
        PLANET DISTANCE TO SUN = 0.10800E 09          DARK SIDE TE
        PLANET ALBEDO, PERCENT = 0.73000E 02          SUB-SOLAR TE
        PLANET RADIUS          = 0.62000E 04          SOLAR TEMPER
        SUN RADIUS             = 0.69530E 06          DELTA ANGLE

   2  SATELLITE ORBIT              0.32810E 04
        INITIAL THETA ANGLE    =-0.60000E 02          NUMBER OF DE
        FINAL THETA ANGLE      = 0.60000E 02          ALTITUDE OF
        INCLINATION ANGLE      = 0.90000E 02          ALTITUDE OF
        OMEGA ANGLE            = 0.31500E 03          INITIAL TIME
        ALPHA(P) ANGLE         =-0.

   3  SATELLITE ORIENTATION
        INITIAL PHI   =  -0.        ORIENTATION( 1=PLANET,2=SPACE
        INITIAL PSI   =  -0.
        INITIAL OMEGA =  -0.

   4  SATELLITE SURFACES      NUMBER OF SURFACES =  3   PERCENT ER
        -1     4     4    -0    -0     SURFACE NO. B
         0.10000E 01  -0.10000E 01  -0.           -0.
                0.960         0.960  -0.           -0.          -
                0.900                -0.           -0.          -
         1     4     4    -0    -0     SURFACE NO. C
        -0.           -0.10000E 01  -0.           -0.
                0.960         0.960  -0.           -0.          -
                0.900                -0.           -0.          -
         1     4     4    -0    -0     SURFACE NO. A
        -0.           -0.            -0.           0.10000E 01
                0.250         0.250  -0.           -0.          -
                0.850                -0.           -0.

   5  OUTPUT VARIABLES     TABLES =  2   FORMAT =  1   CARDS =  0
```

```
PROGRAM USER.

ZMAN CONSTANT = 0.17970E-07
MPERATURE     = 0.23500E 03
MPERATURE     = 0.23500E 03
ATURE         = 0.58083E 04
              =-0.

LTA THETA'S   =    20
PERIAPSIS     = 0.10000E 04
APOAPSIS      = 0.10000E 04
              =-0.

)=  2

OR = 10.0   SURFACE SHADING(-1=NO, 1=YES) =  1.

).10000E 01
).
).

).10000E 01
).
).

).10000E 01
).
).90000E 02

  VARIABLES =  1
```

Fig. B-1 Input Data Written Out

two physical constants that the sun is simulated by a flat disk of a constant radius which is at a uniform black body temperature.

- The DARK SIDE TEMPERATURE and the SUB-SOLAR TEMPERATURE refer to the effective black body planet surface and atmosphere temperature that the satellite surfaces "see." These temperatures do not necessarily refer to the actual planet surface temperature, but to an effective temperature that accounts for the infrared radiation that may be absorbed and reemitted by the planet's atmosphere. The DARK SIDE TEMPERATURE refers to the effective planet temperature of that area not in the sunlight. The SUB-SOLAR TEMPERATURE refers to the effective planet temperature of that area normal to the planet-sun line on the sun side of the planet. The effective planet temperature varies as the cosine of the geocentric angle from the subsolar point to the terminal point of the sunlit portion. Appendix A.1 contains these equations.

- The PLANET ALBEDO PERCENT is the percent of the sun's incident energy that is reflected from the planet's atmosphere and surface. This reflected energy is assumed to be diffuse and may or may not be at the same wavelength as the incident radiation from the sun. An appreciable change in the reflected wavelength will result in a change in the absorptivity of the reflected radiation. The absorptivities of albedo radiation by the satellite surfaces are input in Block 4.

- The STEPHAN-BOLTZMAN CONSTANT can be determined from the references in this appendix with the proper units as described in Appendix C.1.

- DELTA ANGLE δ is the angle between the sun vector $\underline{S}$, and the projection of $\underline{S}$ on the Earth's ecliptic plane (see Fig. B-2). It is measured positive in the "south" direction and negative in the "north" direction which is opposite in sign to the heliocentric latitude tabulated in the references.

Block 2 -- SATELLITE ORBIT. The satellite orbit and the points in this orbit are described by five angles shown in Fig. B-2, the number of $\Delta\theta$'s in the orbit plane, and the altitudes of periapsis and apoapsis.

The following five angles of Block 2 (Fig. B-1) are illustrated in Fig. B-2:

- OMEGA ANGLE Ω is the angle from the projection of the $\underline{S}$ vector on the ecliptic plane to the line of intersection of the ecliptic and orbit planes at the south-to-north crossing of the satellite. The Ω angle is always taken as positive in the counterclockwise direction when viewed from the north pole of the ecliptic ($\underline{P}$).

- ALPHA (P) ANGLE α_p is the angle from the line of intersection of the orbit and ecliptic planes to the periapsis. The α_p angle, in the orbit plane, is always measured positive in the direction of satellite travel from the ascending node.

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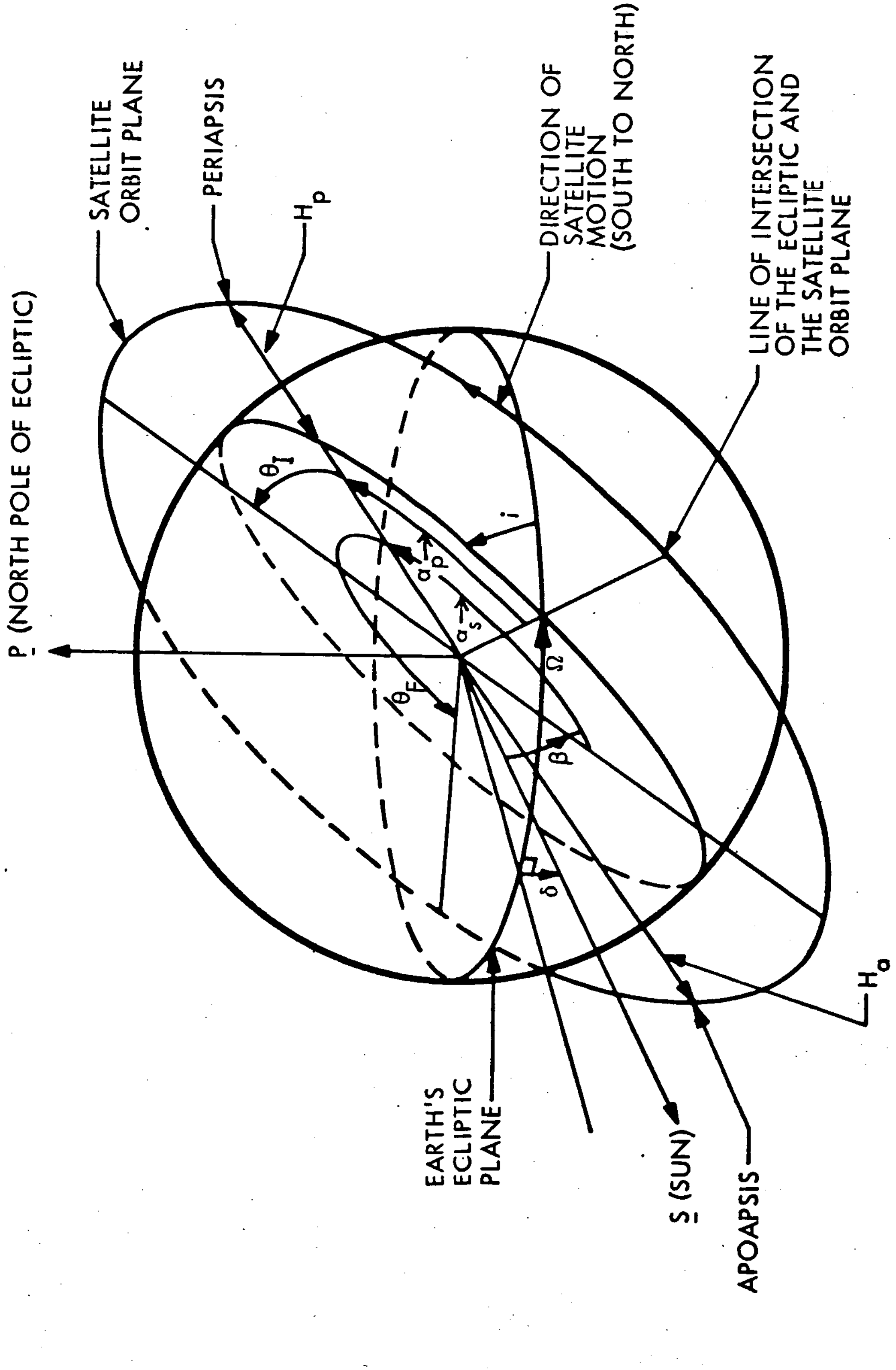

Fig. B-2 Satellite Orbit About a Planet

NOTE: The angles may be more familiar to the reader if they are related to Earth. If the earth's ecliptic plane in Fig. B-2 were the earth's equatorial plane, then δ would be the declination of the apparent sun, Ω would be the apparent right ascension of the ascending node of the satellite, minus the apparent right ascension of the sun, and α_p would be the argument of perigee.

- INCLINATION ANGLE i is the angle that the orbit plane makes with the ecliptic plane. It is measured as the positive angle between the normal to the orbit plane (using the right-hand rule and the direction of satellite travel) and the north pole of the ecliptic.

- INITIAL THETA ANGLE θ_I is the angle measured in the orbit plane from the periapsis to the point in orbit where the heat flux tables start. It is measured positive in the direction of satellite motion.

- FINAL THETA ANGLE θ_F is the angle measured in the orbit plane from the periapsis to the point in orbit where the heat flux tables end. If the heat flux tables are to be periodic, i.e., one complete orbit, then θ_F must equal θ_I. This angle is also measured positive in the direction of satellite motion.

Completion of the interpretation of Block 2 is as follows:

- The NUMBER OF DELTA THETA's refers to the number of times that the total geocentric angle θ_T is divided to obtain the $\Delta\theta$ that the satellite moves in the orbit plane between heat flux calculation points,

  where $\theta_T = \theta_F - \theta_I$

  or $\theta_T = 360$, if $\theta_F = \theta_I$

  Example: NUMBER OF DELTA THETA's = 20

  $$\theta_T = 360$$

  $$\Delta\theta = 360/20 = 18^\circ$$

  In this case, the heat fluxes are calculated for every 18° of satellite motion.

  At those geocentric angles where the satellite enters or leaves the planet shadow, the heat fluxes are calculated in addition to the heat fluxes at each $\Delta\theta$ angle. See the sample problem output in Appendix C.2.

- The orbit time from θ_I to each point in the orbit is then calculated. The orbit time of θ_I is zero if $\theta_T = 360$; however, if $\theta_T < 360$, then the time at θ_I is equal to INITIAL TIME, and the time for each point after θ_I is the INITIAL TIME plus the orbit time from θ_I to each point.

- The ALTITUDE OF APOAPSIS and the ALTITUDE OF PERIAPSIS as input in Block 2 will determine the orbit eccentricity by the true elliptical equations in Appendix A.

Block 3 -- SATELLITE ORIENTATION. INITIAL PHI ϕ_I, INITIAL PSI ψ_I, and INITIAL OMEGA ω_I refer to the rotation of the Orbit Plane Coordinate System to the Central Coordinate System in the following discussion of Block 3 (Fig. B-1). The X", Y", Z" coordinate systems shown in Figs. B-3 and B-4 shall be defined as the Orbit Plane Coordinate System.

For the space-oriented satellite in Fig. B-3, the right-hand orthogonal axes are defined as:

X" = parallel to the north pole of the earth's ecliptic plane, positive in the "north" direction

Y" = directed to complete the right-hand orthogonal set

Z" = parallel to the projection of the sun vector $\underline{S}$ on the earth's ecliptic plane, positive in the direction of the sun

For the planet-oriented satellite in Fig. B-4 the axes are defined as:

X" = perpendicular to the planet radius vector in the satellite orbit plane and measured positive in the direction of satellite motion

Y" = directed to complete the right-hand orthogonal set

Z" = local zenith or the extension of the planet radius vector

The transformation of the Orbit Plane Coordinate System (X", Y", Z") to the Central Coordinate System (X, Y, Z) is shown in Fig. B-5. The Central Coordinate System is the main coordinate system on the satellite to which all

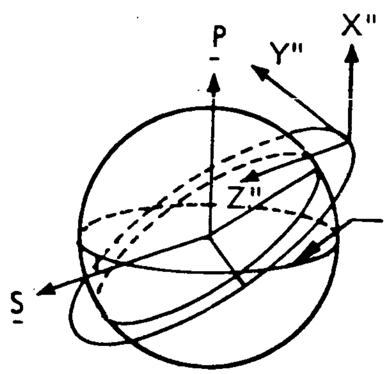

Fig. B-3 Space Oriented

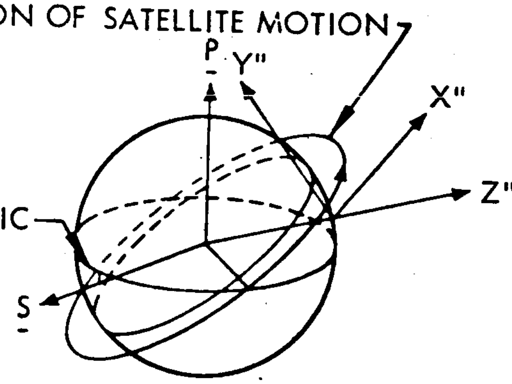

Fig. B-4 Planet Oriented

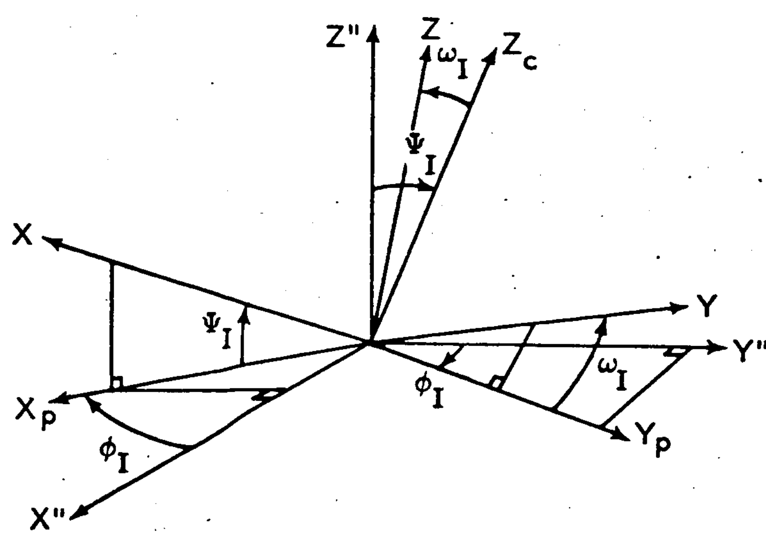

Fig. B-5 Rotation of X"Y"Z" to XYZ

the satellite surfaces described in Block 4 are referred. The angles in Fig. B-5 are taken as positive in the direction shown and are defined in the order of their rotation as:

ϕ_I = the angle about which the X" Y" axes rotated on the Z" axis, positive in the clockwise direction when viewed from the +Z" axis = yaw angle

ψ_I = the angle about which the X_p Z" axes are rotated on the Y_p axis, positive in the clockwise direction when viewed from the $+Y_p$ axis = pitch angle

ω_I = the angle about which the Y_p Z_c axes are rotated on the X axis, positive in the counterclockwise direction when viewed from the +X axis = roll angle

The selection of Orbit Plane Coordinate System in Fig. B-3 or Fig. B-4 is input to the program as ORIENTATION (1 = PLANET, 2 = SUN) which acts as a flag to select the desired satellite orientation in the orbit plane.

The above method of inputting ϕ_I, ψ_I, ω_I, and the satellite orientation enables the program user to "build" the satellite surfaces about the desired Central Coordinate System, and then put the satellite into any desired orbit orientation.

<u>Block 4 -- SATELLITE SURFACES</u>. Block 4 physically describes the satellite surfaces as to their position, size, orientation on the satellite, number of surfaces, emissivity and absorptivity of each surface, and how the view

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factor calculations are to be made by the computer. The interpretation of Block 4 is as follows:

- The NUMBER OF SURFACES indicates the number of sets-of-cards that describe the surface configurations. A set-of-cards consists of four cards and is written out as four lines as shown in Fig. B-1.

- The PERCENT ERROR indicates the finite difference method of calculating the view factor between a unit area in orbit and the planet. This unit area is taken at the altitude of the satellite and is perpendicular to the local zenith. The PERCENT ERROR, as input, will cause the computer program to increase the number of finite difference areas of the planet, thereby increasing the view factor accuracy of this unit area until the actual view factor error is less than the PERCENT ERROR. The error is calculated from the finite difference view factor and the integrated view factor. As the number of finite difference areas of the planet is increased, the computer run time increases. Therefore, the program user may make the trade-off between view factor, or consequently, the heat flux accuracy and the computer run time. Appendix D contains curves that show the accuracy obtainable for a typical planet, the suggested PERCENT ERROR and its effect on the heat fluxes, and the resulting computer run time.

- The SURFACE SHADING (-1 = NO, 1 = YES) acts as a flag which causes the program to check all the satellite surfaces which may be shielded or partially shaded by other satellite surfaces. The computer run time is decreased if the shading check routine in the program is not executed. The computer run time increase due to the shading check routine is discussed in Appendix D.

Each of the four cards in each set-of-cards is written out in Fig. B-1 in the same format as it is input in Fig. B-6. The following description of symbols shown in Fig. B-6 refers to each of the satellite surface geometric configurations shown in Figs. B-7, B-8, and B-9.

- Surface type:

  ± 1 = rectangle

  ± 2 = disk

  ± 3 = trapezoid or triangle

  Where: Positive values indicate the direction of the surface normal in the direction of the +Z' axis, and negative values indicate the direction of the surface normal in the direction of the -Z' axis.

- α = Z' distance from the origin to the plane

- β_{min} = minimum distance in the β direction

- β_{max} = maximum distance in the β direction

- α_{min} = minimum distance (or angle) in the α direction

MODULE	ORGN.	BLDG.	FAC.	JOB NUMBER	DATE OF REQUEST	DISPATCH NUMBER	PROGRAM
PROGRAMMER		ORGN.	PHONE				F

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

1 XXXXX±XX XXXXX±XX XXXXX±XX
BLOCK 1
LENGTH CONVERSION FACTOR
GRAVITATIONAL CONSTANT PLANET
DISTANCE TO THE SU

XXXXXX XXXXX±XX XXXXX±XX XXXXX±XX
PLANET NAME
STEPHAN-BOLTZMAN CONSTANT
PLANET TEMP. DARK SIDE
PLANET TEM SUB-SOLAR

2 XXXXX±XX XXXXX±XX XXXXX±XX
BLOCK 2
LENGTH CONVERSION FACTOR
INITIAL THETA, θ_I
FINAL TH

XXXXX±XX XXXXX±XX XXXXX±XX
ALPHA(P), α_p
NO. OF $\Delta\theta$'S
ALTITUDE PERIAPSIS

3 ±XXXXX±XX ±XXXXX±XX ±XXXXX±XX
BLOCK 3
INITIAL PHI, ϕ_I
INITIAL PSI, ψ_I
INITIAL OM

4 XXXXX±XX XXXXX±XX XXXXX±XX
BLOCK 4
NO. OF SETS OF CARDS FOR VEHICLE SURFACE
VIEW FACTOR ERROR, PERCENT
SHAD SURFA INCID

±X XXX XXX XXX XXX ← COMMENTS, I
SURFACE TYPE
NA
NG
NYB
NVX

±XXXXX±XX ±XXXXX±XX ±XXXXX±XX ±XXXXX±XX
α
β MIN.
γ MIN.
β MA

X.XXX X.XXX ±XXXXX±XX ±XXXXX±XX
SOLAR ABSORPTIVITY
ALBEDO ABSORPTIVITY
R(Z)
R(Y)

X.XXX ±XXXXX±XX ±XXXXX±XX
INFRARED α=INFRARED ϵ
ϕ
ϕ

5 XXXXX±XX XXXXX±XX XXXXX±XX
BLOCK 5
TABLES
FORMAT 1 (FLEXSTA)
CARDS

1 (SOLAR+ALBEDO, PLANETSHINE - TOTAL ABSORBED / SOLAR+ALBEDO, PLANETSHINE - DIRECT INCIDENT)
2 (SOLAR, ALBEDO, PLANETSHINE - TOTAL ABSORBED / SOLAR, ALBEDO, PLANETSHINE - DIRECT INCIDENT)

0 NO CAR
1 TOTAL
2 DIRECT
3 BOTH (

ROGRAM INPUT	OPER. CONTROL NO.	DATE NEEDED	PRIORITY	LOCKHEED MISSILES & SPACE COMPANY A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION 80 COLUMN WORKSHEET FORM LMSC 2374 PAGE ____ OF ____

41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

XXXXX±XX XXXXX±XX XXXXX±XX

PLANET ALBEDO PERCENT — PLANET RADIUS — SUN RADIUS

XXXXX±XX ±XXXXX±XX

P., SUN TEMP. — DELTA, δ

XXXXX±XX XXXXX±XX

TA, θF — INCLINATION, i — OMEGA, Ω

XXXXX±XX XXXXX±XX

AT — ALTITUDE AT APOAPSIS — AT — INITIAL TIME

XXXXX±XX

EGA, ωI — ORIENTATION (1 = PLANET ORIENTED; 2 = SPACE ORIENTED)

NG OF VEHICLE CES FROM NT RADIATION (1 = YES, THERE IS SHADING; -1 = NO, SURFACES ARE NOT SHADED)

DESIRED ⟶

±XXXXX±XX

X MAX

±XXXXX±XX

R(X)

±XXXXX±XX

ω

XXXXX±XX

VARIABLES

0 (NOTHING)

1 {MAXIMUM / ORBIT ECCENTRICITY / ORBIT PERIOD / PERCENT OF ORBIT TIME IN THE SUN / BETA ANGLE / ALPHA(S) ANGLE, α_s / RADIATION CONSTANTS, $\mathcal{F}_{i-j}\ A_i$}

S

BSORBED

VCIDENT

OTAL AND DIRECT)

Fig. B-6 Program Input

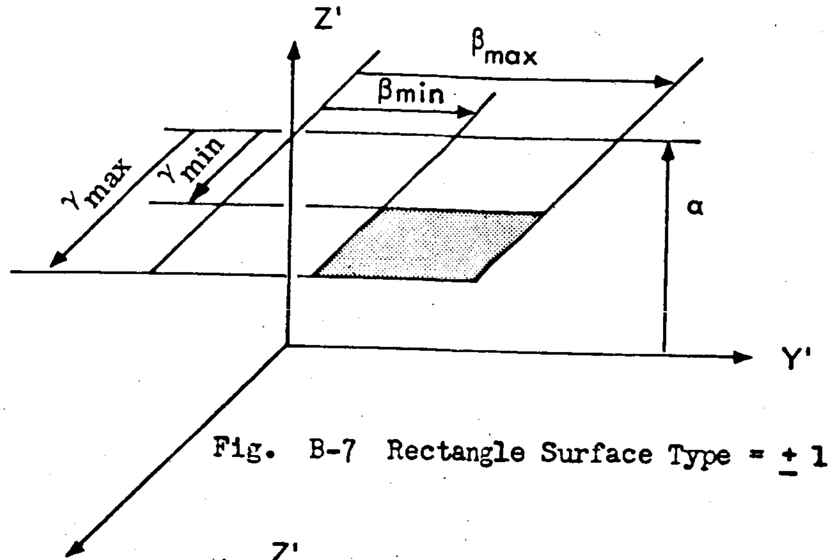

Fig. B-7 Rectangle Surface Type = ± 1

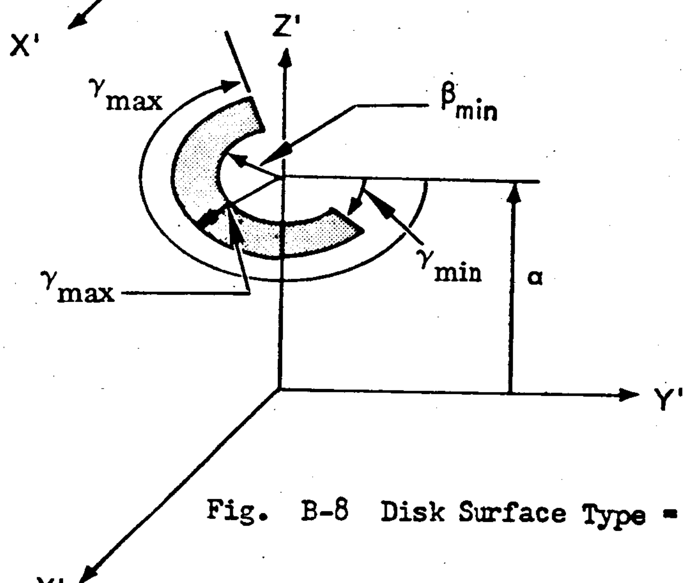

Fig. B-8 Disk Surface Type = ± 2

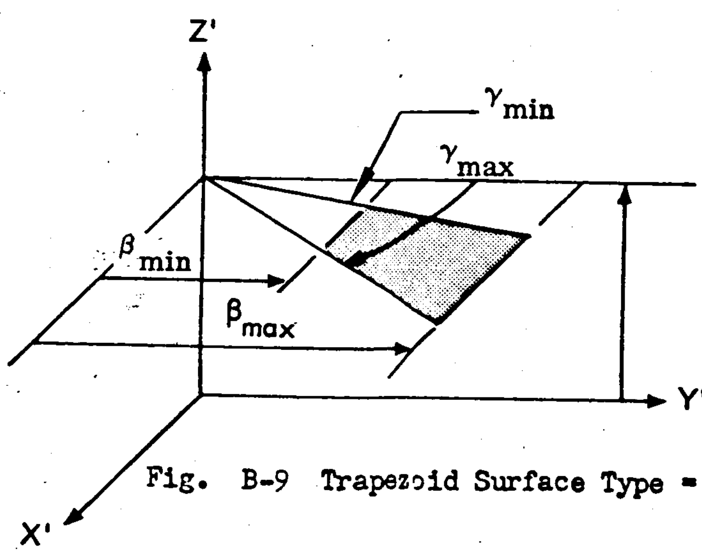

Fig. B-9 Trapezoid Surface Type = ± 3

- α_{max} = maximum distance (or angle) in the α direction

  NOTE: The angles must be measured positive in the clockwise direction from the Y' axis as viewed from the Z' axis

The location and orientation of each Surface Coordinate System (X', Y', Z') is specified in terms of the Central Coordinate System (X, Y, Z) as shown in Figs. B-10 and B-11.

- R(X) = distance from the Central Coordinate System origin to the Surface Coordinate System origin in the X direction

- R(Y) = same in the Y direction

- R(Z) = same in the Z direction

- ϕ = the angle about which the X and Y axes are rotated on the Z axis, positive in the clockwise direction when viewed from the +Z axis = yaw angle

- ψ = the angle about which the X_p and Z axes are rotated on the Y_p axis, positive in the clockwide direction when viewed from the $+Y_p$ axis = pitch angle

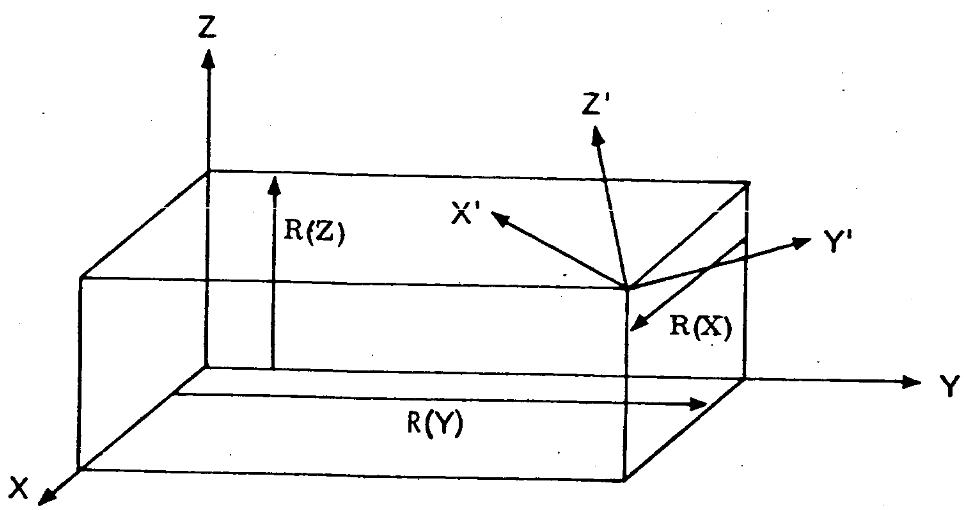

Fig. B-10 Location of X'Y'Z' Origin

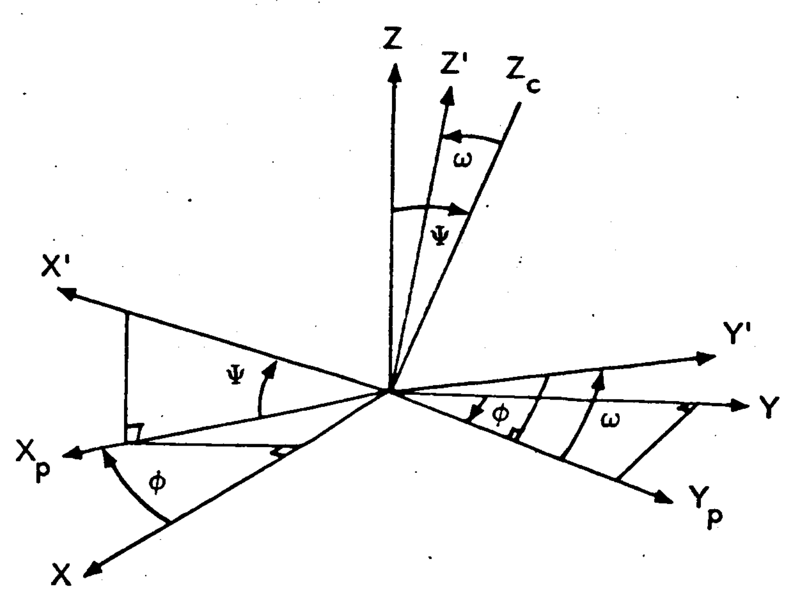

Fig. B-11 Orientation of X'Y'Z' Coordinate System

- ω = the angle about which the Y_p and Z axes are rotated on the X' axis, positive in the counterclockwise direction when viewed from the +X' axis = roll angle

The surface described by each set-of-cards may be divided into more than one node by specifying $NV\beta$ and $NV\alpha$ as shown in Fig. B-12. If $NV\beta$ or $NV\alpha$ is greater than one, more than one set of heat fluxes for this surface will be generated. The number of sets of heat flux tables for each surface is $NV\beta$ times $NV\alpha$ = N. The Hollerith (identification written out for each surface) will be the same for all N nodes of a surface. Therefore, these heat flux tables are produced in the order that the nodes are broken down. This is best explained in the example of Fig. B-12,

where, $NV\beta$ = number of nodes in the β direction

$NV\alpha$ = number of nodes in the α direction

Also, all nodes of a surface have the same absorptivity and emissivity.

Each of the nodes described are subdivided into elements for the finite difference view factor calculation by specifying $N\beta$ and $N\alpha$ as shown in Fig. B-12,

where, $N\beta$ = number of elements in the β direction

$N\alpha$ = number of elements in the α direction

In Fig. B-12, the nodes and elements are defined as:

- b = width of node in the β direction = $(\beta_{max} - \beta_{min})/NV\beta$
- g = width of node in the α direction = $(\alpha_{max} - \alpha_{min})/NV\alpha$
- Δ b = width of element in the β direction = $b/N\beta$

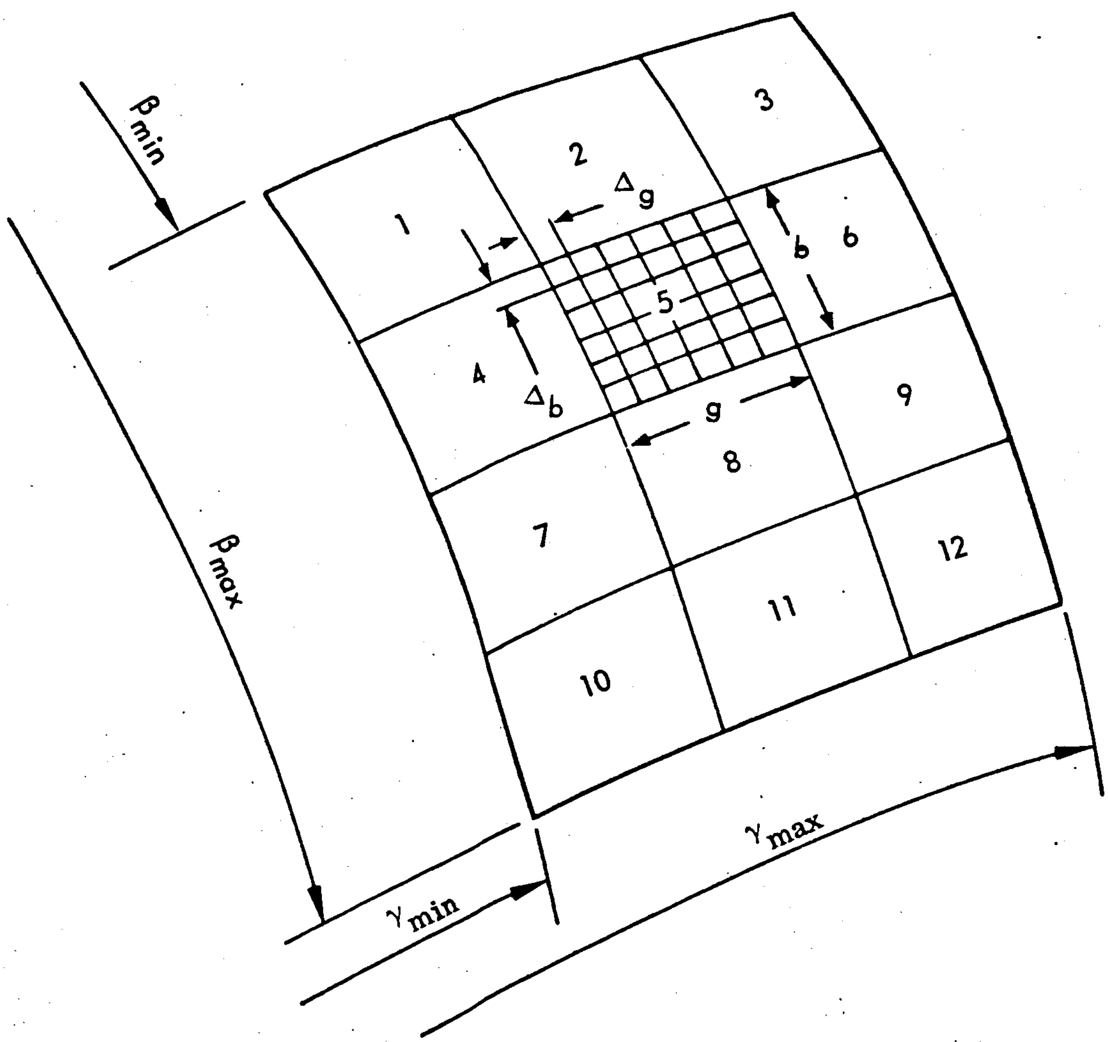

Fig. B-12 Example of Node and Element Distribution

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- Δg = width of element in the α direction = $g/N\alpha$

The nodes are numbered 1 -- 12 in the order that heat flux tables will be produced.

In this example, $NV\beta = 4$, $NV\alpha = 3$, $N\beta = 5$, $N\alpha = 6$ so that:

- Number of nodes/surface = $NV\beta$ times $NV\alpha$ = 12
- Number of elements/node = $N\beta$ times $N\alpha$ = 30
- Number of elements/surface = ($N\beta$ times $N\alpha$)($NV\beta$ times $NV\alpha$) = 360

In this computer program, the maximum number of nodes for all the vehicle surfaces is 20. While the maximum number of elements for all the vehicle surfaces is 711 to 963, depending upon the number of elements that the planet is divided into.

The first card of each set-of-cards contains a Hollerith Field with which the program user can identify the resulting heat flux tables for this surface. The order of inputting the set-of-cards is the order in which the heat flux tables will be listed.

The solar, albedo, and planetshine absorptivity must be entered for each surface to obtain the absorbed heat fluxes for this surface. The planetshine absorptivity is assumed to equal the surface emissivity from which the radiation exchange factor between the node is calculated, and also the radiation of this node to space.

Block 5 -- OUTPUT VARIABLES. Block 5 (Fig. B-1) determines the form and kind of output from the calculations made by the computer.

The TABLES is a flag to determine if the albedo flux for a surface is to be added to the solar flux for that surface. This is done to conserve the number of heat flux tables output. The added fluxes do not imply that the solar and albedo absorptivities are equal.

The FORMAT is a flag to select the desired output format of the heat flux tables that corresponds to the particular thermal analyzer computer program that the program user has available.

The CARDS is a flag to provide punched IBM cards of the output heat flux tables listed. This flag is set by the program user to do the following:

0 = no cards will be punched out

1 = all the total absorbed heat flux tables will be punched

2 = all the direct incident heat flux tables will be punched

3 = all the heat flux tables will be punched

The punched cards will be identical to the tables listed.

The VARIABLES is a flag set by the program user to output the following values for the vehicle nodes, if desired:

- Percent time in the sun
- Orbit eccentricity
- Solar constant

- Orbit period
- α_S angle
- Beta angle
- Radiation constants

These values will be discussed in Appendix B.2.

B.2 DEFINITION OF OUTPUT VARIABLES

The variables that are output in Fig. B-13 are constant for the particular orbit in which the specified satellite surfaces are about a specific planet.

The PERCENT TIME IN THE SUN is the percent of the satellite orbit time that the satellite is exposed to direct solar radiation.

The ORBIT ECCENTRICITY is the eccentricity calculated from the true elliptical orbit equations contained in Appendix A.

The SOLAR CONSTANT is the maximum solar incident radiation, per unit area, at the planet's distance from the sun. The units will be heat/length^2 - time, and the value will be calculated from the variables input by the program user.

BETA ANGLE β is the angle whose magnitude is the complement of the acute angle between the planet-sun line and a normal to the satellite-orbit plane. The normal to the satellite-orbit plane is directed by the right-hand rule using the satellite motion as the direction of rotation. The sign of β

```
PERCENT TIME IN THE SUN =   75.5                         ALPHA(S) ANGLE =   0.

ORBIT ECCENTRICITY = 0.                                  BETA ANGLE =   -45.0

SOLAR CONSTANT = 0.84770E 03

ORBIT PERIOD = 0.65969E 04

RADIATION CONSTANTS FOR VEHICLE NODES.   SPACE = NUMBER 21
K( 1, 2) =   0.39898E-06
K( 1, 3) =   0.32750E-06
K( 2, 3) =   0.32756E-06
K( 2, 4) =   0.
K( 1,21) =   0.96241E-06
K( 2,21) =   0.96241E-06
K( 3,21) =   0.55834E-06
```

Fig. B-13 Variables Written Out

will be positive if the satellite appears to move in a counterclockwise direction around the planet when satellite motion is viewed from the sun. See Fig. B-2.

ALPHA (S) ANGLE α_S is the angle between the projection of $\underline{S}$ on the satellite-orbit plane and the periapsis of the satellite orbit. It is measured positive in the direction of satellite motion. See Fig. B-2.

The RADIATION CONSTANTS FOR VEHICLE NODES. SPACE = NUMBER 21 readout is the heading for a list of the radiation interchange factors between the nodes and also to space. These values are obtained from the solution of the radiation constant matrix shown in Appendix A and multiplied by the Stephan-Boltzmann constant, σ, to give a tabulated value of $A_i F_{i-j} \sigma$. The K(i,j) indicates this radiation constant between node i and j where the node numbers sequence corresponds to the order of input of the surface description in input Block 4 (Fig. B-1). Space, with an emissivity and absorptivity of one, is assigned number 21.

The ORBIT PERIOD is the satellite period as calculated from the true elliptical orbit equations contained in Appendix A.

The Flexsta Thermal Analyzer format is used to output in tables the heat fluxes as a function of orbit time. In this particular format the tables are numbered at the extreme left of the output sheet on the same line as the orbit period if the tables are periodic. The right-hand column is the heat fluxes corresponding to the orbit times in the left-hand column. The last heat flux is equal to the first heat flux for periodic tables.

The TOTAL ABSORBED refers to the solar, albedo, or planetshine radiation that is absorbed by the entire node area which includes the absorbed reflection from other surfaces. Therefore, the units of these heat fluxes would be heat/time.

The DIRECT INCIDENT refers to the solar, albedo, or planetshine radiation that is directly from these sources for a unit area of the node. Therefore, the units of these heat fluxes would be heat/length^2-time.

B.3 PROGRAM DIAGNOSTICS

The following diagnostics are written out before the program is stopped in an effort to aid the program user in locating the variable that is not acceptable to the program:

- The ERRØR IN BLØCK IDENTIFICATIØN NUMBER indicates that the block identification number is greater than five.

- The ERRØR IN BLØCK 2, PERIAPSIS GREATER THAN APØAPSIS is a self-explanatory diagnostic.

- The ERRØR IN BLØCK 2, THETA FINAL IS LESS THAN THETA INITIAL is a self-explanatory diagnostic, $\theta_F < \theta_I$, which the program will not accept.

- The ERRØR IN BLØCK 3, VEHICLE ØRIENTATIØN indicates that the orientation flag entered was greater than 2 so that no vehicle orientation could be selected.

- The ERRØR IN BLØCK 5 could indicate one of two things: (1) the flag for TABLES selection was greater than 2, or (2) the flag for FØRMAT selection was greater than 2.

- The ERRØR IN SURFACE TYPE, SUBRØUTINE VECTØR indicates that the variable entered for the surface type in Block 4 was greater than the absolute value of 6.

- The TØØ MANY ELEMENTS indicates that the total number of finite difference elements exceeded the number of core storage locations in the computer. This diagnostic will occur if the total number of elements is greater than 963 and may occur if the total number of elements is between 711 and 963.

- The TØØ MANY NØDES indicates that the number of nodes for which heat fluxes are to be calculated is greater than twenty (20).

- The RADK MATRIX IS SINGULAR. PRØGRAM CANNØT CØNTINUE occurs during the inversion of the non-orthogonal matrix for the heat flux calculation. It may occur due to zero emissivities or absorptivities, and, also if view factor matrix or the albedo percent is zero.

B.4 UNCITED REFERENCES

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6. Nautical Almanac Office, United States Naval Observatory, The American Ephemeris and Nautical Almanac, United States Government Printing Office Washington, D. C., 1965

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Appendix C
PROGRAM SAMPLE PROBLEM

C.1 INPUTTING THE COMPUTER PROGRAM

The computer program is completely independent of units of time, heat, length, and temperature. Therefore, the program user must decide what set of units are to be used, and then must be consistent in inputting variables in these units.

The computer program input format is shown in Fig. B-6. The input is divided into 5 blocks, with all blocks required for the initial orbital case. To run additional cases, only the block(s) containing the changed input data and Block 5 need to be input to the program because the program retains the last information input into each block. There is no limit to the number of restarts that can be run.

<u>Block 1.</u> Block 1 consists of information about the sun and the planet that will need to be determined in the system of units decided upon.

a. Units of Length

The planet radius, the sun radius, and the distance to the sun are each multiplied by the "length" conversion factor entered in Block 1 of the program. This multiplication by the program will convert these values to the length units used by the program and output in the heat flux tables.

Example 1:

$$(.3965 \times 10^4) \times (.528 \times 10^4) = .209 \times 10^8$$

$$\text{Planet Radius Statute Miles} \times \text{"Length" conversion factor, ft/S.M.} = (\text{Planet Radius, ft.})$$

Input to the computer in Block 1 — Stored and used by the computer

The planet gravitational constant and the Stephan-Boltzmann Constant, both of which contain length units, are not multiplied by the "length" conversion factor or its inverse.

Therefore, the length units in the planet gravitational constant and the Stephan-Boltzmann Constant input to the program must correspond to the converted length units of the planet radius, the sun radius, and the planet distance as stored by the computer.

Example 2: (corresponding to Example 1)

Gravitational constant, ft/(time)^2

Stephan-Boltzmann Constant, heat/time-ft^2-(temp)^4

b. **Units of Temperature**

The planet's dark side temperature, the planet's subsolar temperature, the effective temperature of the sun, and the temperature units used in the Stephan-Boltzmann Constant <u>must</u> all have corresponding units which <u>must</u> be in absolute degrees.

Example 3:

Planet's dark side temperature = 450°R

Planet's subsolar temperature = 4600R

Effective temperature of the sun = 10,455°R

Stephan-Boltzmann Constant, Heat/Time-(Length)^2-(°R)^4

c. Units of Time

The units of time used in the planet's gravitational constant will be the units of time used in the calculation of the orbit period and the time between each heat flux calculation point in the table output. The units of time used in the Stephan-Boltzmann Constant will be the time rate at which heat is being transmitted to or is being absorbed by the satellite surfaces.

d. Units of Heat or Energy

The unit of heat in the output heat fluxes will be the unit input in the Stephan-Boltzmann Constant. The δ angle is input in degrees for $-90^\circ < \delta < 90^\circ$.

Block 2. Block 2 consists of information about the satellite's orbit about the planet specified in Block 1.

The altitudes at periapsis and apoapsis, as input to the program, are each multiplied by the "length" conversion unit entered in Block 2. The program will convert these altitudes to the length units that must correspond to the length units used by the program as defined in Block 1.

Example 4: (corresponding to Example 1)

$$(.300 \times 10^3) \times (.60761 \times 10^4) = .1822 \times 10^7$$

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Satellite Altitude at periapsis, nautical miles	x	"length" conversion factor ft/nm	=	Planet altitude at periapsis, ft
		Input to the computer in Block 2		Stored and used by the computer

The time units of the initial time must correspond to the units of time used in the gravitational constant in Block 1.

All angles in Block 2 are to be input as positive with all the angles input in degrees. If the heat fluxes are desired for the entire orbit, i.e., periodic, the initial theta angle, θ_I, <u>must</u> equal the final theta angle, θ_T. However, if heat fluxes are desired for only part of the orbit, then θ_T <u>must</u> be greater than θ_I, i.e., $\theta_T > \theta_I$. See Appendix B.1 for the definition of the angles in Block 2.

The number of heat flux calculation points in the satellite orbit are input as the number of θ's. The maximum number for this value is 36 which would calculate the heat fluxes for every 10° of theta angle for a 360° orbit.

<u>Block 3.</u> Block 3 consists of information about the satellite's orientation in the orbit described in Block 2.

The initial phi, psi, and omega angles (ϕ_I, ψ_I, ω_I) may be positive or negative in sign, but must all be in degrees.

The satellite orientation in the orbit plane is input as -1 for a planet-oriented satellite, or as 1 for a space-oriented satellite as shown in Figs. B-1 and B-6.

Block 4. Block 4 consists of the description of the satellite surfaces to which the heat fluxes are to be calculated and how the planet view factors are to be calculated.

> Note: Four cards are necessary for the complete description of every surface and these four cards are called a "set-of-cards".

The units of length input in this block must correspond to the units of length used by the program as defined in input Block 1.

Example 5: (corresponding to Example 1)

For a rectangular surface; α, β_{min}, γ_{min}, β_{max}, γ_{max}, R (X), R (Y), and R (Z) must all have length units in ft.

All length measurements can be input as $\pm$ values. The γ angle must be input as positive angles, however, the ϕ, ψ, and ω angles may be $\pm$, but all must be in degrees.

The number of Δ elements, and the number of nodes can be calculated as follows:

$$\text{Number of Nodes} = NN = \sum_{J=1}^{J=N} (NV\beta)_j x (NV\gamma)_j$$

Where: N = number of sets-of-cards

j = jth set-of-cards

$$\text{Number of } \Delta \text{ Elements} = NDE = \sum_{J=1}^{J=N} (N\beta)(N\gamma)(NV\beta)(NV\gamma)_j$$

Where the maximum values are: $NN \leq 20$

$NDE \leq 675$ to 963

NDE may be greater than 675 provided the planet elements are less in number than their maximum number of 963 as shown in Appendix D.

Block 5. Block 5 consists of information about the output form of the tables, their format, and if punched card output of these tables is desired. Also, if a listing of output variables is desired.

This block must be input with the correct desired output for every restart that is run.

> NOTE: For the special case of narrow shadow angle i.e., high percentage sun time) if none of the computed points in an orbit fall within the shadow, the printed output will indicate 100% sun time and the program will not make the extra in-and-out-of shadow calculation.

The following sample problem (Appendix C.2) illustrates the use of the Generalized Computer Program.

C.2 GENERAL HEAT FLUX PROGRAM SAMPLE PROBLEM

To illustrate the utilization of the computer program, two sets of heat fluxes will be obtained by running an initial case and a restart in the following sample problems.

C.2.1 INITIAL PROBLEM CASE

Problem: Determine the total absorbed heat fluxes on three satellite surfaces in an elliptical orbit about Venus on 2 December 1965.

Given: The satellite orbit plane (Fig. C-1) will be inclined to the Earth's ecliptic by 60°, and will pass about 30° (measured in the ecliptic) from Venus' subsolar point. The periapsis will occur in the planet's shadow 45 geocentric degrees north of the ecliptic plane. The satellite will be traveling south to north at periapsis, 600 KM, and north to south at apoapsis, 1000 Km.

The space oriented satellite surfaces will be positioned in orbit so that the Z and Y axis lie in the plane of the ecliptic, the -X axis is directed toward the center of the planet when the satellite is at the ascending node position in the orbit plane. See Fig. C-2.

Solution: With the above information, the Generalized Computer Program can be input and total absorbed heat fluxes shall be in Btu/hr-

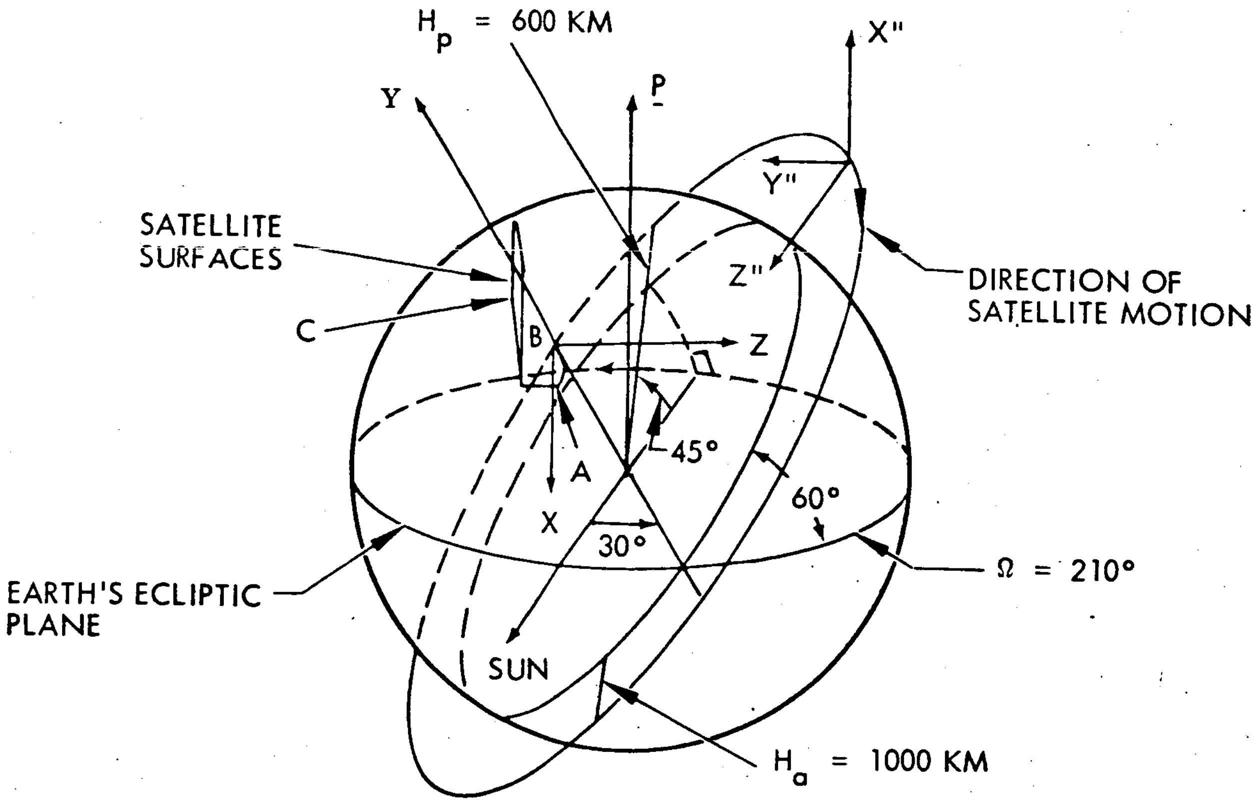


Fig. C-1 Initial Problem Case, Satellite Orbit

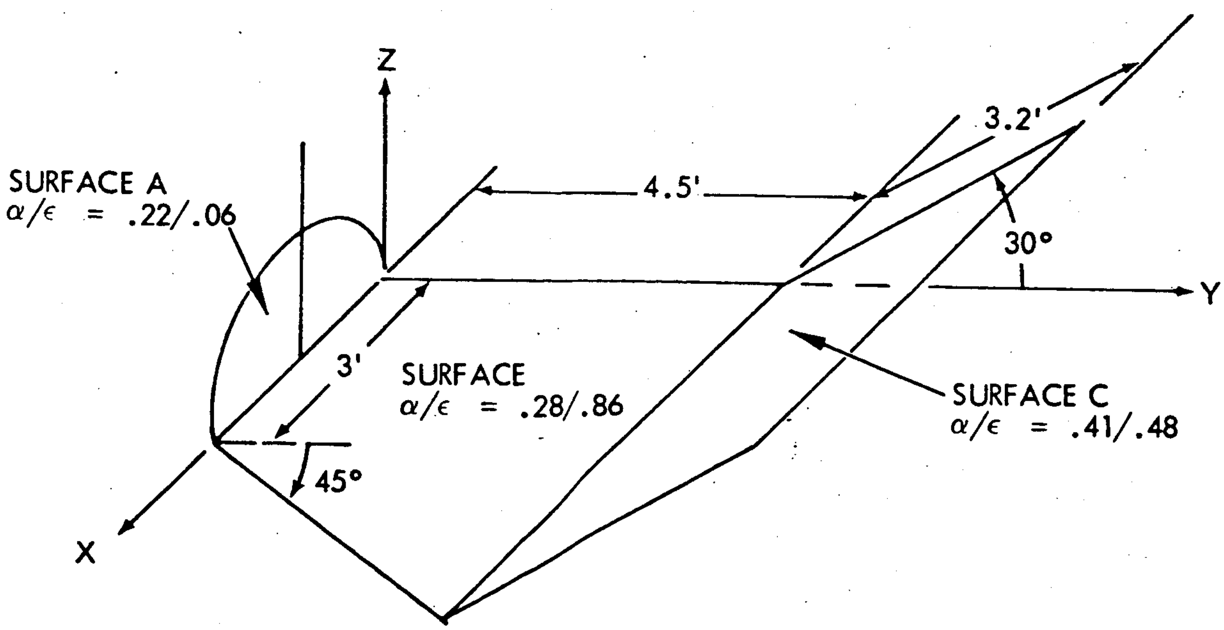


Fig. C-2 Initial Problem Case, Satellite Surfaces

ft^2 for the heat fluxes, and the orbit time shall be in seconds. Complete orbital fluxes will be output, and each satellite surface will be considered as one node.

<u>Block 1 Input:</u> Block 1 is input as follows: The length conversion unit will be 3280.8 ft/Km, and the gravitational constant is 28.9 ft/sec^2 from Ref. 6 in Appendix B. The planet distance to the sun on 2 December 1965 is 0.723, 702, 600 astronomical units (a.u.), where 1 a.u. = 149.5×10^6 Km. Therefore, the distance to the sun is input as $(.7237026)(149.5 \times 10^6) = 108.1935 \times 10^6$ Km

The planet radius of 6200 Km, the planet albedo of 70 percent, and the constant effective planet temperature of 235°K are input to the program. See Ref. 4 of Appendix B. The sun radius of 695,300 Km, and surface temperature of 5808.3°K gave the mean solar constant measured at the Earth, so these values are used for Venus. The Stephan-Boltzmann Constant, 1.797×10^{-8} BTU/hr-ft^2-°K^4, is used from Ref. 2 of Appendix B.

Delta angle δ is the negative of the heliocentric latitude tabulated in Ref. 6 of Appendix B. For 2 December 1965, the latitude is $-2^\circ\ 10'\ 13.9''$, so δ is input as +2.172 degrees, i.e., the sun vector is south of the ecliptic plane.

<u>Block 2 Input:</u> Block 2 is input as follows: Again, the length con-

version factor is 3280.8 ft/Km due to the given altitudes at periapsis and apoapsis of 600 Km and 1000 Km, respectively.

The α_p angle can be calculated from spherical trigonometry and Fig. C-3.

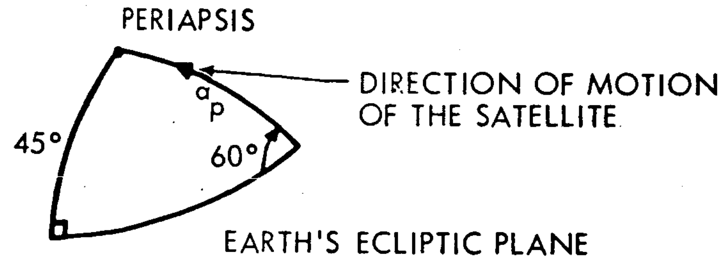
Omega angle Ω will be $30^\circ + 180^\circ = 210^\circ$ to the ascending node of the satellite. Also, the inclination i will be $90^\circ + 30^\circ = 120^\circ$ by definition.

The heat fluxes are desired for the entire orbit with no starting point specified, so $\theta_I = \theta_F = 0$. Let the number $\Delta\theta$'s in the orbit plane equal to 20 so that the heat flux will be calculated every 18 geocentric degrees.

Block 3 Input: Block 3 is input as follows: The satellite surfaces are space-oriented, so that $\phi_I = 180^\circ$, $\psi_I = 0^\circ$, and $\omega_I = -120^\circ$.

Block 4 Input: Block 4 is input as follows: Each of the three satellite surfaces is referred to the X, Y, Z coordinate system in Fig. C-2.

Referring to Fig. C-4, the variables of surface A are determined as:



$$\text{SIN}\ \alpha_p = \text{SIN } 45°/\text{SIN } 60°$$

$$\text{or}\ \alpha_p = \text{SIN}^{-1}\left(\frac{.70711}{.86603}\right) = 54.8°$$

Fig. C-3 Alpha (p)

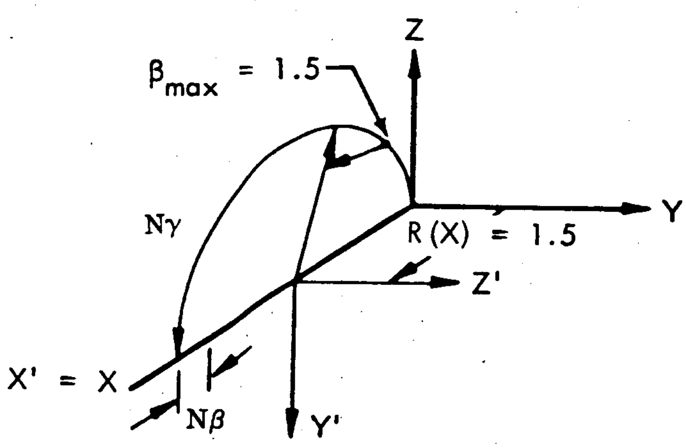


Fig. C-4 Disk

170

2 = surface type	$270^\circ = \gamma$ max
3 = $N\beta$	$1.5 = \beta$ max
6 = $N\gamma$	R(X) = 1.5
$90^\circ = \gamma$ min	$\omega = 90^\circ$

The solar absorptivity and albedo absorptivity are equal to 0.22, and the emissivity is equal to 0.06. The input values for $NV\beta$, $NV\gamma$, α, β min, R(Y), R(Z), ϕ, and ψ are left blank. Therefore, these values are zero for surface A.

Referring to Fig. C-5, the variables of surface β are determined as:

3 = surface type	$45^\circ = \gamma$ max
5 = $N\beta$	R(Y) = -3.
6 = $N\gamma$	$.28 = \alpha_s$ (Solar absorptivity)
3 = β min	$.2 = \alpha_A$ (albedo absorptivity)
7.5 = β max	$.86 = \epsilon$

The input values of $NV\beta$, $NV\gamma$, α, γ min, R(X), R(Z), ϕ, ψ, and ω are zero for surface B.

Referring to Fig. C-6, the variables of surface C are determined as:

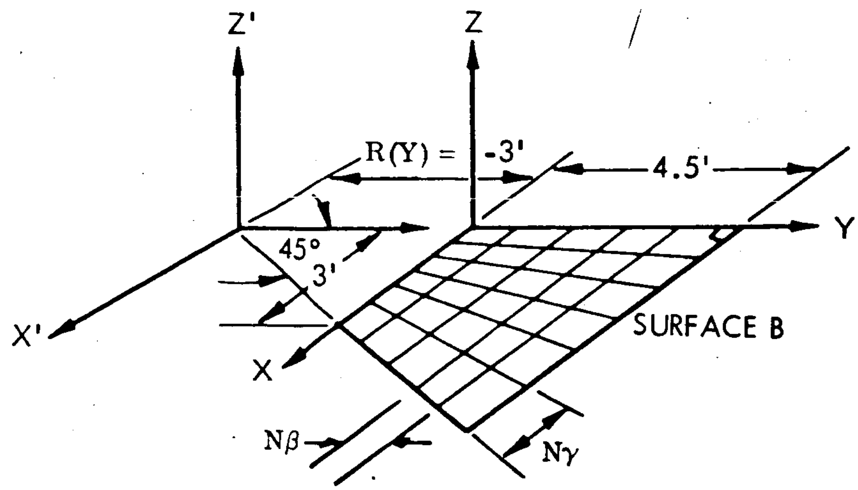


Fig. C-5 Trapezoid

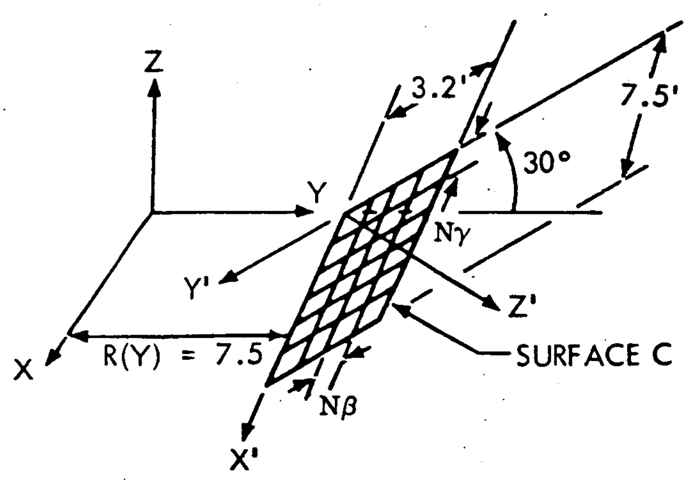


Fig. C-6 Rectangle

-1 = surface type	$-120^{\circ} = \omega$
$4 = N\beta$	$.41 = \alpha_s$
$6 = N\gamma$	$.41 = \alpha_A$
$-3.2 = \beta_{min}$	$.48 = \epsilon$
$7.5 = \gamma_{max}$	
7.5 = R (Y)	

The input values of $NV\beta$, $NV\gamma$, α, β_{max}, R(x), R(z), ϕ, and ψ are zero for surface C.

Block 5 Input. Block 5 is input as follows: The output of the tables is the combined solar and albedo heat fluxes in the Flexsta format. No card output is required, but the variables are to be printed out.

The input cards for the initial case are punched as shown in Fig. C-7, and are input to the computer in the order shown. The first card, the comment card, must follow the * DATA card for every initial case. The output of the initial problem case is shown in Fig. C-11.

C.2.2 RESTART PROBLEM CASE

Problem: Determine the total absorbed heat fluxes on four satellite surfaces for part of a circular orbit about Venus on 2 December 1965.

Given: The satellite orbit plane will be inclined to the Earth's ecliptic by 60°, and will pass about 30° (measured in the ecliptic) from Venus' subsolar point. The periapsis will occur in the sun, 10 geocentric degrees (measured in the satellite orbit plane) south of the ecliptic plane. The satellite will be traveling south to north at periapsis which is at an altitude of 350 n.m.

The planet oriented satellite surfaces will be positioned in orbit so that the z and y axis lie in the plane of the ecliptic, the -y axis is directed toward the center of the planet when the satellite is at the ascending node position in the orbit plane. See Fig. C-8.

The heat fluxes are necessary only while the satellite is north of the ecliptic plane, and the tables are to start at the ascending node when the orbit time is 1000 seconds.

The satellite surfaces are described in Fig. C-9 in which surfaces A, B, and C are the same as shown in Fig. C-2. Surface D, for which two separate heat fluxes are desired, is added in Fig. C-9.

Solution: With the above information, the restart problem case (inputting information following the initial problem) can be completed. The system of units for the output shall again be BTU/hr.-ft^2 for the heat fluxes and the orbit time in seconds.

MODULE	ORGN.	BLDG.	FAC.	JOB NUMBER	DATE OF REQUEST	DISPATCH NUMBER	PROGRAM
							INIT
PROGRAMMER		ORGN.	PHONE				CASE

1–5	6	7	8–10	11–12	13–15	16–20	21–30	31–40
VENU	S		ORB	IT	ER,	2 DE	C.1965, CO	NFIGURATIO
1					328	08+04	289 +02	10819+09
V	E	N	US		179	7 -07	235 +03	235 +03
2					328	08+04		
					548	+02	20 +02	600 +03
3					180	+03		-120 +03
4					3	+01	10 +02	1 +01
2			3		6		DISK	SURFACE A,
							90 +02	15 +01
			22			.22		
			06					
3			5		6		TRAP.	SURF.B, A
					3	+01		75 +01
			28			28		-3 +01
			86					
-1			4		6		RECT.	SURF.C, A
				-	32	+01		
			41			41		75 +01
			48					
5					1	+01	1 +01	

	OPER. CONTROL NO.	DATE NEEDED	PRIORITY	LOCKHEED MISSILES & SPACE COMPANY A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION 80 COLUMN WORKSHEET FORM LMSC 2374 PAGE ____ OF ____
AL PROBLEM INPUT DATA				

41–50	51–60	61–70	71–80
NS NO. 1,2	SATELLI	TE ORBITS	NO. B,C
73 +02	62 +04	6953 +06	
58083+04	2172 +01		
120 +03	210 +03		
1000 +04			
2 +01			
A/E=.221/.	06		
270 +03			
15 +01			
-90 +02			
/E =.281/.8	6		
45 +01			
/E =.411/.4	8		
75 +01			
-120 +03			
1 +01			

Fig. C-7 Initial Problem Case, Input Data

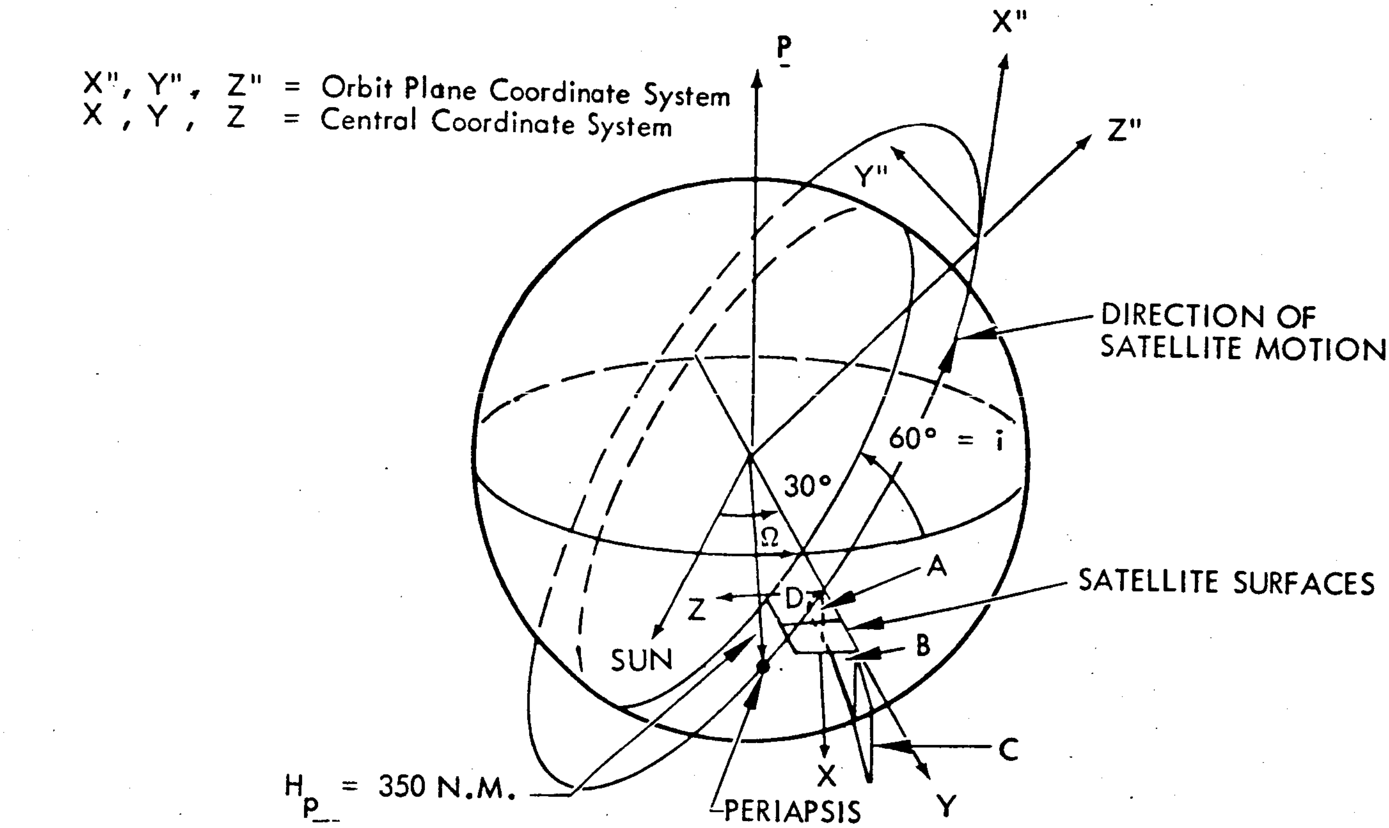


Fig. C-8 Restart Problem Case, Satellite Orbit

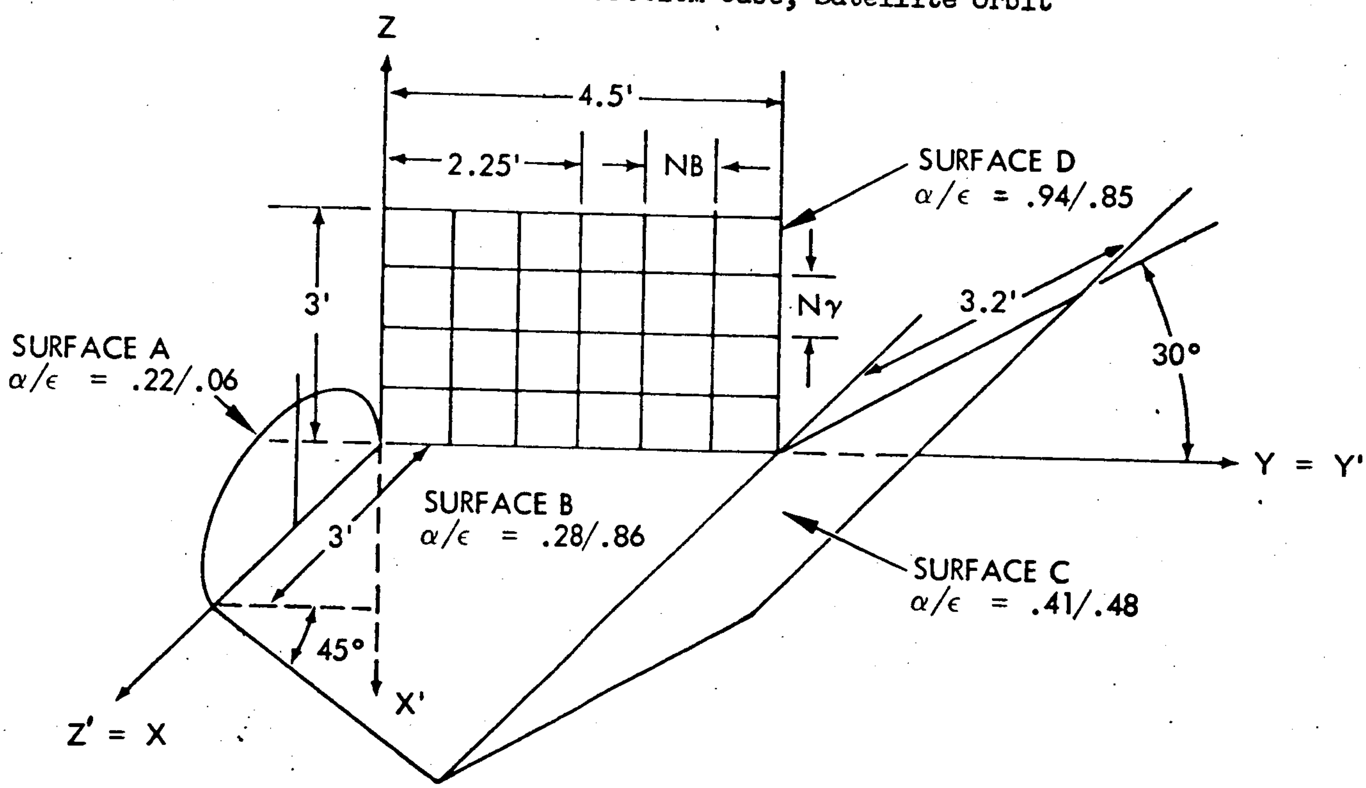


Fig. C-9 Restart Problem Case, Satellite Surfaces

Block 1 Input. Block 1 is not input for this restart because the planet data has not changed from the initial case.

Block 2 Input. Block 2 is input as follows: The length conversion factor is 6076.1 ft/n.m. with the apoapsis and periapsis of 350 n.m. The α_p angle will be 350° by definition, with θ_I of 10° for the initial value in the heat flux tables at the ascending node. The end of the tables at the ecliptic plane, θ_F, will be 190°. The inclination angle, i, will be 60°, and the Ω will be 30° by definition.

Let the number of delta theta's, $\Delta\theta$'s, be 12, so that the heat flux will be calculated every 15 geocentric degrees. The initial time is 1000 sec.

Block 3 Input. Block 3 is input as follows: The satellite surfaces are planet-oriented, therefore, $\phi_I = 120°$, $\psi_I = 0$, and $\omega_I = 90°$.

Block 4 Input. Block 4 is input as follows: Each of the four satellite surfaces is referred to the x, y, z coordinate system in Figs. C-1 or C-7. Surface A, B, and C are the same for this restart as the initial case.

Surface D is to be broken into two nodes as shown in Fig. C-7, so the variables of surface D are determined as:

1 = surface type	
3 = $N\beta$	4.5 = β_{max}
4 = $N\gamma$	.94 = α_s
2 = $NV\beta$	.90 = α_A
1 = $NV\gamma$	.85 = ϵ
-3 = γ_{min}	ψ = -90°

The input values of α, β_{min}, γ_{max}, R(x), R(y), R(z), ϕ, and ω are zero.

<u>Block 5 Input.</u> Block 5 is input as follows: The output of the tables is to be the solar and albedo in separate tables in the Flexsta format. No card output is required, but the variables are described.

The input cards for the restart are punched as shown in Fig. C-10, and must follow directly the Block 5 card of the initial case shown in Fig. C-7. If this is the only restart, nothing will follow the Block 5 card in Fig. C-10. The output from the restart is shown in Fig. C-11.

C.2.3 DISCUSSION OF SAMPLE PROBLEM

For the initial case, the satellite heat flux tables start at periapsis which is in the planet's shadow. The satellite leaves the planet shadow at 370. sec and enters it at 4634.3 sec. Note that the rectangle surface, C, receives a small amount of albedo at the terminal point after the satellite has entered the planet's shadow and that a small amount of this reflected energy is absorbed by the disk and the trapezoid.

For the restart case, a statement is written out after Block 5 of the input variables to explain the zero printed out in the variable output. The initial satellite time was 1000 sec and the final time was 4059.6 sec which occurred 180 geocentric degrees later. The satellite entered the planet's shadow at 2697.2 sec at which time both the albedo and solar fluxes become zero. The planetshine for all nodes remain constant which is expected for a planet-oriented-circular-satellite over a constant temperature planet. However, note the difference in the solar, albedo, and planetshine both total absorbed and direct incident radiation for the two nodes on surface D. This difference for identical node size, shape, and surface optical properties is due to the different shading of these nodes by adjacent surfaces. It should be recalled by the program user that the heat flux calculations are based on the average view factors for each node, hereby making it desirable to make node areas small for more precise local surface area heat fluxes.

The computer run time for this sample problem, both the initial case and the restart, was 0.057 hrs. from the "on-line" printer.

MODULE	ORGN.	BLDG.	FAC.	JOB NUMBER		DATE OF REQUEST	DISPATCH NUMBER	PROGRAM RE CASE
PROGRAMMER		ORGN.	PHONE					
2			607	61 +04	10	+02	190	+03
			350	+03	12	+02	350	+03
3			120	+03			90	+02
4			4	+01	10	+02	1	+01
2		3	6			DISK, SURFACE A		
					90	+02	15	+01
	22			22				
	06							
3		5	6			TRAPEZOID, SURF		
			3	+01			75	+01
	28			28			-3	+01
	86							
-1		4	6			RECTANGLE, SURF		
			-32	+01				
	41			41			75	+01
	48							
1		3	4	2		1RECTANGLES, SUR		
					-3	+01	45	+01
	94			90				
	85						-90	+02
5			2	+01	1	+01		

START PROBLEM
, INPUT DATA

OPER. CONTROL NO. | DATE NEEDED | PRIORITY

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
80 COLUMN WORKSHEET
FORM LMSC 2374
PAGE ______ OF ______

60	+02	30	+02
350	+03	1000	+04
1	+01		
, A/E = .22		/.06	
270	+03		
15	+01		
-90	+02		
ACE B, A/E		= .28/.86	
45	+01		
ACE C, A/E		= .41/.48	
75	+01		
-120	+03		
FACE D, .94, .90, .85			
1	+01		

Fig. C-10 Restart Problem Case, Input Data

```
VENUS ORBITER, 2 DEC.1965, CONFIGURACTIONS NO. 1,2   SATELLITE ORBITS NO. B,C

  1  PLANET DATA FOR VENUS          0.32808E 04
       GRAVITATIONAL CONSTANT = 0.28900E 02        STEPHAN-BOLTZMAN CONSTANT = 0.17970E-07
       PLANET DISTANCE TO SUN = 0.10819E 09        DARK SIDE TEMPERATURE     = 0.23500E 03
       PLANET ALBEDO, PERCENT = 0.73000E 02        SUB-SOLAR TEMPERATURE     = 0.23500E 03
       PLANET RADIUS          = 0.62000E 04        SOLAR TEMPERATURE         = 0.58083E 04
       SUN RADIUS             = 0.69530E 06        DELTA ANGLE               = 0.21720E 01

  2  SATELLITE ORBIT                0.32808E 04
       INITIAL THETA ANGLE    =-0.                 NUMBER OF DELTA THETA'S   =  20
       FINAL THETA ANGLE      =-0.                 ALTITUDE OF PERIAPSIS     = 0.60000E 03
       INCLINATION ANGLE      = 0.12000E 03        ALTITUDE OF APOAPSIS      = 0.10000E 04
       OMEGA ANGLE            = 0.21000E 03        INITIAL TIME              =-0.
       ALPHA(P) ANGLE         = 0.54800E 02

  3  SATELLITE ORIENTATION
       INITIAL PHI    = 180.0        ORIENTATION( 1=PLANET,2=SPACE)=  2
       INITIAL PSI    =  -0.
       INITIAL OMEGA  =-120.0

  4  SATELLITE SURFACES       NUMBER OF SURFACES =  3   PERCENT ERROR = 10.0   SURFACE SHADING(-1=NO, 1=YES) =  1.
      2     3     6   -0    -ODISK SURFACE A, A/E=.22/.06
     -0.              -0.             0.90000E 02   0.15000E 01   0.27000E 03
           0.220         0.220  -0.             -0.             0.15000E 01
           0.060                -0.             -0.            -0.90000E 02
      3     5     6   -0    -0TRAP. SURF.B, A/E =.28/.86
     -0.               0.30000E 01  -0.              0.75000E 01   0.45000E 01
           0.280         0.280  -0.             -0.30000E 01  -0.
           0.860                -0.             -0.            -0.
     -1     4     6   -0    -0RECT. SURF.C, A/E =.41/.48
     -0.             -0.32000E 01  -0.             -0.             0.75000E 01
           0.410         0.410  -0.              0.75000E 01  -0.
           0.480                -0.             -0.            -0.12000E 03

  5  OUTPUT VARIABLES      TABLES =  1   FORMAT =  1   CARDS =  0   VARIABLES =  1
```

Fig. 7-11 Program Sample Problem Output

PERCENT TIME IN THE SUN = 67.4

ALPHA(S) ANGLE = 220.6

ORBIT ECCENTRICITY = 0.0286

BETA ANGLE = -24.6

SOLAR CONSTANT = 0.84475E 03

ORBIT PERIOD = 0.63238E 04

RADIATION CONSTANTS FOR VEHICLE NODES. SPACE = NUMBER 21

```
K( 1, 2) =  0.85826E-10
K( 1, 3) =  0.13155E-09
K( 2, 3) =  0.32670E-09
K( 3, 4) =  0.
K( 1,21) =  0.35932E-08
K( 2,21) =  0.28291E-07
K( 3,21) =  0.20648E-06
```

1

SOLAR + ALBEDO, TOTAL ABSORBED
DISK SURFACE A, A/E=.22/.06

0.63238E 04

0.	0.
0.29877E 03	0.
0.37000E 03	0.
0.37000E 03	0.14070E 02
0.59914E 03	0.14077E 02
0.90263E 03	0.15447E 02
0.12104E 04	0.67918E 02
0.15234E 04	0.15579E 03
0.18421E 04	0.23397E 03
0.21662E 04	0.30906E 03
0.24951E 04	0.29137E 03
0.28276E 04	0.23928E 03
0.31610E 04	0.15406E 03
0.34962E 04	0.81632E 02
0.38287E 04	0.29267E 02
0.41576E 04	0.14788E 02
0.44817E 04	0.14085E 02
0.46343E 04	0.14071E 02
0.46343E 04	0.50483E-03
0.48003E 04	0.
0.51133E 04	0.
0.54211E 04	0.
0.57246E 04	0.
0.60250E 04	0.
0.63238E 04	0.

2

PLANETSHINE, TOTAL ABSORBED
DISK SURFACE A, A/E=.22/.06

0.63238E 04

0.	0.77027E 00
0.29877E 03	0.16089E 01
0.37000E 03	0.18778E 01
0.37000E 03	0.18778E 01
0.59914E 03	0.28261E 01
0.90263E 03	0.42706E 01
0.12104E 04	0.55344E 01
0.15234E 04	0.67877E 01
0.18421E 04	0.73223E 01
0.21662E 04	0.83234E 01
0.24951E 04	0.74835E 01
0.28276E 04	0.64869E 01
0.31610E 04	0.49589E 01
0.34962E 04	0.37706E 01
0.38287E 04	0.23752E 01
0.41576E 04	0.12915E 01
0.44817E 04	0.59823E 00
0.46343E 04	0.43380E-00
0.46343E 04	0.43380E-00
0.48003E 04	0.33635E-00
0.51133E 04	0.33226E-00
0.54211E 04	0.32649E-00
0.57246E 04	0.28628E-00
0.60250E 04	0.31116E-00
0.63238E 04	0.77027E 00

3	0.63238E 04		SOLAR + ALBEDO, TOTAL ABSORBED
	0.	0.	TRAP. SURF.B, A/E =.28/.86
	0.29877E 03	0.	
	0.37000E 03	0.	
	0.37000E 03	0.30151E 01	
	0.59914E 03	0.30166E 01	
	0.90263E 03	0.32546E 01	
	0.12104E 04	0.83692E 01	
	0.15234E 04	0.19105E 02	
	0.18421E 04	0.36294E 02	
	0.21662E 04	0.56186E 02	
	0.24951E 04	0.75603E 02	
	0.28276E 04	0.89714E 02	
	0.31610E 04	0.90244E 02	
	0.34962E 04	0.70307E 02	
	0.38287E 04	0.35333E 02	
	0.41576E 04	0.57718E 01	
	0.44817E 04	0.30183E 01	
	0.46343E 04	0.30152E 01	
	0.46343E 04	0.10818E-03	
	0.48003E 04	0.	
	0.51133E 04	0.	
	0.54211E 04	0.	
	0.57246E 04	0.	
	0.60250E 04	0.	
	0.63238E 04	0.	

4	0.63238E 04		PLANETSHINE, TOTAL ABSORBED
	0.	0.64010E 01	TRAP. SURF.B, A/E =.28/.86
	0.29877E 03	0.61735E 01	
	0.37000E 03	0.64687E 01	
	0.37000E 03	0.64687E 01	
	0.59914E 03	0.62435E 01	
	0.90263E 03	0.68544E 01	
	0.12104E 04	0.78696E 01	
	0.15234E 04	0.10751E 02	
	0.18421E 04	0.14760E 02	
	0.21662E 04	0.19131E 02	
	0.24951E 04	0.23946E 02	
	0.28276E 04	0.29414E 02	
	0.31610E 04	0.34749E 02	
	0.34962E 04	0.38158E 02	
	0.38287E 04	0.39319E 02	
	0.41576E 04	0.38213E 02	
	0.44817E 04	0.34497E 02	
	0.46343E 04	0.31871E 02	
	0.46343E 04	0.31871E 02	
	0.48003E 04	0.29020E 02	
	0.51133E 04	0.23139E 02	
	0.54211E 04	0.17610E 02	
	0.57246E 04	0.12626E 02	
	0.60250E 04	0.88144E 01	
	0.63238E 04	0.64010E 01	

5

SOLAR + ALBEDO, TOTAL ABSORBED
RECT. SURF.C, A/E =.41/.48

0.63238E 04	
0.	0.
0.29877E 03	0.
0.37000E 03	0.
0.37000E 03	0.41776E 04
0.59914E 03	0.41797E 04
0.90263E 03	0.42228E 04
0.12104E 04	0.42163E 04
0.15234E 04	0.41940E 04
0.18421E 04	0.42013E 04
0.21662E 04	0.42095E 04
0.24951E 04	0.42358E 04
0.28276E 04	0.43784E 04
0.31610E 04	0.46315E 04
0.34962E 04	0.48568E 04
0.38287E 04	0.48131E 04
0.41576E 04	0.43688E 04
0.44817E 04	0.41820E 04
0.46343E 04	0.41777E 04
0.46343E 04	0.14989E-00
0.48003E 04	0.
0.51133E 04	0.
0.54211E 04	0.
0.57246E 04	0.
0.60250E 04	0.
0.63238E 04	0.

6

PLANETSHINE, TOTAL ABSORBED
RECT. SURF.C, A/E =.41/.48

0.63238E 04	
0.	0.24220E 03
0.29877E 03	0.16170E 03
0.37000E 03	0.14309E 03
0.37000E 03	0.14309E 03
0.59914E 03	0.86754E 02
0.90263E 03	0.40796E 02
0.12104E 04	0.11784E 02
0.15234E 04	0.39363E 01
0.18421E 04	0.39774E 01
0.21662E 04	0.45274E 01
0.24951E 04	0.77970E 01
0.28276E 04	0.25483E 02
0.31610E 04	0.62351E 02
0.34962E 04	0.12030E 03
0.38287E 04	0.19551E 03
0.41576E 04	0.28550E 03
0.44817E 04	0.36748E 03
0.46343E 04	0.40504E 03
0.46343E 04	0.40504E 03
0.48003E 04	0.43541E 03
0.51133E 04	0.46708E 03
0.54211E 04	0.46258E 03
0.57246E 04	0.40760E 03
0.60250E 04	0.33392E 03
0.63238E 04	0.24220E 03

1 SOLAR + ALBEDO, DIRECT INCIDENT
DISK SURFACE A, A/E=.22/.06

0.63238E 04	
0.	0.
0.29877E 03	0.
0.37000E 03	0.
0.37000E 03	0.
0.59914E 03	0.
0.90263E 03	0.15678E 01
0.12104E 04	0.68894E 02
0.15234E 04	0.18162E 03
0.18421E 04	0.28151E 03
0.21662E 04	0.37733E 03
0.24951E 04	0.35377E 03
0.28276E 04	0.28565E 03
0.31610E 04	0.17494E 03
0.34962E 04	0.81537E 02
0.38287E 04	0.15641E 02
0.41576E 04	0.
0.44817E 04	0.
0.46343E 04	0.
0.46343E 04	0.
0.48003E 04	0.
0.51133E 04	0.
0.54211E 04	0.
0.57246E 04	0.
0.60250E 04	0.
0.63238E 04	0.

2 PLANETSHINE, DIRECT INCIDENT
DISK SURFACE A, A/E=.22/.06

0.63238E 04	
0.	0.28327E 01
0.29877E 03	0.70488E 01
0.37000E 03	0.83764E 01
0.37000E 03	0.83764E 01
0.59914E 03	0.13032E 02
0.90263E 03	0.19991E 02
0.12104E 04	0.26042E 02
0.15234E 04	0.31972E 02
0.18421E 04	0.34483E 02
0.21662E 04	0.39192E 02
0.24951E 04	0.35210E 02
0.28276E 04	0.30440E 02
0.31610E 04	0.23103E 02
0.34962E 04	0.17304E 02
0.38287E 04	0.10477E 02
0.41576E 04	0.50777E 01
0.44817E 04	0.15511E 01
0.46343E 04	0.65994E 00
0.46343E 04	0.65994E 00
0.48003E 04	0.10852E-00
0.51133E 04	0.
0.54211E 04	0.
0.57246E 04	0.
0.60250E 04	0.36483E-00
0.63238E 04	0.28327E 01

3

SOLAR + ALBEDO, DIRECT INCIDENT
TRAP. SURF.B, A/E =.28/.86

0.63238E 04	
0.	0.
0.29877E 03	0.
0.37000E 03	0.
0.37000E 03	0.
0.59914E 03	0.
0.90263E 03	0.33644E-00
0.12104E 04	0.75556E 01
0.15234E 04	0.23829E 02
0.18421E 04	0.52944E 02
0.21662E 04	0.87403E 02
0.24951E 04	0.12555E 03
0.28276E 04	0.15508E 03
0.31610E 04	0.16003E 03
0.34962E 04	0.12506E 03
0.38287E 04	0.60546E 02
0.41576E 04	0.50266E 01
0.44817E 04	0.
0.46343E 04	0.
0.46343E 04	0.
0.48003E 04	0.
0.51133E 04	0.
0.54211E 04	0.
0.57246E 04	0.
0.60250E 04	0.
0.63238E 04	0.

4

PLANETSHINE, DIRECT INCIDENT
TRAP. SURF.B, A/E =.28/.86

0.63238E 04	
0.	0.36114E 01
0.29877E 03	0.33585E 01
0.37000E 03	0.35010E 01
0.37000E 03	0.35010E 01
0.59914E 03	0.32032E 01
0.90263E 03	0.33095E 01
0.12104E 04	0.36929E 01
0.15234E 04	0.52266E 01
0.18421E 04	0.76156E 01
0.21662E 04	0.10129E 02
0.24951E 04	0.13322E 02
0.28276E 04	0.16945E 02
0.31610E 04	0.20583E 02
0.34962E 04	0.22924E 02
0.38287E 04	0.23888E 02
0.41576E 04	0.23352E 02
0.44817E 04	0.21106E 02
0.46343E 04	0.19465E 02
0.46343E 04	0.19465E 02
0.48003E 04	0.17676E 02
0.51133E 04	0.13969E 02
0.54211E 04	0.10517E 02
0.57246E 04	0.74593E 01
0.60250E 04	0.51377E 01
0.63238E 04	0.36114E 01

5	0.63238E 04		SOLAR + ALBEDO, DIRECT INCIDENT RECT. SURF.C, A/E =.41/.48
	0.	0.	
	0.29877E 03	0.	
	0.37000E 03	0.	
	0.37000E 03	0.42440E 03	
	0.59914E 03	0.42461E 03	
	0.90263E 03	0.42897E 03	
	0.12104E 04	0.42775E 03	
	0.15234E 04	0.42453E 03	
	0.18421E 04	0.42440E 03	
	0.21662E 04	0.42440E 03	
	0.24951E 04	0.42722E 03	
	0.28276E 04	0.44222E 03	
	0.31610E 04	0.46885E 03	
	0.34962E 04	0.49256E 03	
	0.38287E 04	0.48875E 03	
	0.41576E 04	0.44381E 03	
	0.44817E 04	0.42485E 03	
	0.46343E 04	0.42441E 03	
	0.46343E 04	0.15227E-01	
	0.48003E 04	0.	
	0.51133E 04	0.	
	0.54211E 04	0.	
	0.57246E 04	0.	
	0.60250E 04	0.	
	0.63238E 04	0.	
6	0.63238E 04		PLANETSHINE, DIRECT INCIDENT RECT. SURF.C, A/E =.41/.48
	0.	0.20988E 02	
	0.29877E 03	0.13960E 02	
	0.37000E 03	0.12332E 02	
	0.37000E 03	0.12332E 02	
	0.59914E 03	0.73974E 01	
	0.90263E 03	0.33402E 01	
	0.12104E 04	0.76242E 00	
	0.15234E 04	0.22044E-01	
	0.18421E 04	0.	
	0.21662E 04	0.21531E-03	
	0.24951E 04	0.32274E-00	
	0.28276E 04	0.19040E 01	
	0.31610E 04	0.51752E 01	
	0.34962E 04	0.10261E 02	
	0.38287E 04	0.16855E 02	
	0.41576E 04	0.24718E 02	
	0.44817E 04	0.31867E 02	
	0.46343E 04	0.35135E 02	
	0.46343E 04	0.35135E 02	
	0.48003E 04	0.37776E 02	
	0.51133E 04	0.40527E 02	
	0.54211E 04	0.40137E 02	
	0.57246E 04	0.35367E 02	
	0.60250E 04	0.28970E 02	
	0.63238E 04	0.20988E 02	

```
2  SATELLITE ORBIT              0.60761E 04
     INITIAL THETA ANGLE       = 0.10000E 02        NUMBER OF DELTA THETA'S    =  12
     FINAL THETA ANGLE         = 0.19000E 03        ALTITUDE OF PERIAPSIS      = 0.35000E 03
     INCLINATION ANGLE         = 0.60000E 02        ALTITUDE OF APOAPSIS       = 0.35000E 03
     OMEGA ANGLE               = 0.30000E 02        INITIAL TIME               = 0.10000E 04
     ALPHA(P) ANGLE            = 0.35000E 03

3  SATELLITE ORIENTATION
     INITIAL PHI   = 120.0        ORIENTATION( 1=PLANET,2=SPACE)=  1
     INITIAL PSI   =  -0.
     INITIAL OMEGA =  90.0

4  SATELLITE SURFACES      NUMBER OF SURFACES =  4   PERCENT ERROR = 10.0   SURFACE SHADING(-1=NO, 1=YES) =  1.
     2    3    6   -0   -0DISK, SURFACE A, A/E =.22/.06
    -0.            -0.              0.90000E 02   0.15000E 01   0.27000E 03
          0.220          0.220  -0.               -0.           0.15000E 01
          0.060                 -0.               -0.          -0.90000E 02
     3    5    6   -0   -0TRAPAZOID, SURFACE B, A/E =.28/.86
    -0.             0.30000E 01  -0.               0.75000E 01   0.45000E 01
          0.280          0.280  -0.              -0.30000E 01  -0.
          0.860                 -0.               -0.           -0.
    -1    4    6   -0   -0RECTANGLE, SURFACE C, A/E =.41/.48
    -0.            -0.32000E 01  -0.              -0.            0.75000E 01
          0.410          0.410  -0.               0.75000E 01  -0.
          0.480                 -0.               -0.          -0.12000E 03
     1    3    4    2    1RECTANGLES, SURFACE D, .94,.90,.85
    -0.            -0.              -0.30000E 01   0.45000E 01  -0.
          0.940          0.900  -0.               -0.           -0.
          0.850                 -0.              -0.90000E 02  -0.

5  OUTPUT VARIABLES     TABLES =  2   FORMAT =  1   CARDS =  0   VARIABLES =  1

PERCENT TIME IN SUN NOT CALCULATED FOR PARTIAL ORBIT
```

PERCENT TIME IN THE SUN = 0.

ALPHA(S) ANGLE = 8.0

ORBIT ECCENTRICITY = 0.

BETA ANGLE = 24.6

SOLAR CONSTANT = 0.84472E 03

ORBIT PERIOD = 0.61192E 04

RADIATION CONSTANTS FOR VEHICLE NODES. SPACE = NUMBER 21

```
K( 1, 2) =  0.90866E-10
K( 1, 3) =  0.13438E-09
K( 1, 4) =  0.60143E-09
K( 1, 5) =  0.15181E-09
K( 2, 3) =  0.36834E-09
K( 2, 4) =  0.35372E-08
K( 2, 5) =  0.54458E-08
K( 3, 4) =  0.19469E-08
K( 3, 5) =  0.32105E-08
K( 4, 5) =  0.50153E-09
K( 5, 6) =  0.
K( 1,21) =  0.28314E-08
K( 2,21) =  0.19189E-07
K( 3,21) =  0.20126E-06
K( 4,21) =  0.94958E-07
K( 5,21) =  0.93484E-07
```

1

SOLAR, TOTAL ABSORBED
DISK, SURFACE A, A/E =.22/.06

0.10000E 04	0.40168E 03
0.12550E 04	0.45769E 03
0.15099E 04	0.40754E 03
0.17649E 04	0.28473E 03
0.20199E 04	0.14511E 03
0.22748E 04	0.28650E 02
0.25298E 04	0.33156E 02
0.26972E 04	0.34997E 02
0.26972E 04	0.
0.27848E 04	0.
0.30397E 04	0.
0.32947E 04	0.
0.35497E 04	0.
0.38046E 04	0.
0.40596E 04	0.

2

ALBEDO, TOTAL ABSORBED
DISK, SURFACE A, A/E =.22/.06

0.10000E 04	0.15355E 02
0.12550E 04	0.13740E 02
0.15099E 04	0.11190E 02
0.17649E 04	0.78776E 01
0.20199E 04	0.40390E 01
0.22748E 04	0.68566E 00
0.25298E 04	0.18090E-01
0.26972E 04	0.
0.26972E 04	0.
0.27848E 04	0.
0.30397E 04	0.
0.32947E 04	0.
0.35497E 04	0.
0.38046E 04	0.
0.40596E 04	0.

3

PLANETSHINE, TOTAL ABSORBED
DISK, SURFACE A, A/E =.22/.06

0.10000E 04	0.39391E-00
0.12550E 04	0.39391E-00
0.15099E 04	0.39391E-00
0.17649E 04	0.39391E-00
0.20199E 04	0.39391E-00
0.22748E 04	0.39391E-00
0.25298E 04	0.39391E-00
0.26972E 04	0.39391E-00
0.26972E 04	0.39391E-00
0.27848E 04	0.39391E-00
0.30397E 04	0.39391E-00
0.32947E 04	0.39391E-00
0.35497E 04	0.39391E-00
0.38046E 04	0.39391E-00
0.40596E 04	0.39391E-00

4

		SOLAR, TOTAL ABSORBED
0.10000E 04	0.71053E 02	TRAPAZOID, SURFACE B, A/E =.28/.86
0.12550E 04	0.12853E 03	
0.15099E 04	0.31052E 03	
0.17649E 04	0.40945E 03	
0.20199E 04	0.43732E 03	
0.22748E 04	0.44244E 03	
0.25298E 04	0.42718E 03	
0.26972E 04	0.40453E 03	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

5

		ALBEDO, TOTAL ABSORBED
0.10000E 04	0.29734E 02	TRAPAZOID, SURFACE B, A/E =.28/.86
0.12550E 04	0.27354E 02	
0.15099E 04	0.23104E 02	
0.17649E 04	0.17274E 02	
0.20199E 04	0.10271E 02	
0.22748E 04	0.30008E 01	
0.25298E 04	0.11812E-00	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

6

		PLANETSHINE, TOTAL ABSORBED
0.10000E 04	0.93990E 01	TRAPAZOID, SURFACE B, A/E =.28/.86
0.12550E 04	0.93990E 01	
0.15099E 04	0.93990E 01	
0.17649E 04	0.93990E 01	
0.20199E 04	0.93990E 01	
0.22748E 04	0.93990E 01	
0.25298E 04	0.93990E 01	
0.26972E 04	0.93990E 01	
0.26972E 04	0.93990E 01	
0.27848E 04	0.93990E 01	
0.30397E 04	0.93990E 01	
0.32947E 04	0.93990E 01	
0.35497E 04	0.93990E 01	
0.38046E 04	0.93990E 01	
0.40596E 04	0.93990E 01	

7

		SOLAR, TOTAL ABSORBED
0.10000E 04	0.43845E 02	RECTANGLE, SURFACE C, A/E =.41/.48
0.12550E 04	0.51032E 02	
0.15099E 04	0.49869E 02	
0.17649E 04	0.87320E 03	
0.20199E 04	0.27535E 04	
0.22748E 04	0.44784E 04	
0.25298E 04	0.59949E 04	
0.26972E 04	0.68131E 04	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

8

		ALBEDO, TOTAL ABSORBED
0.10000E 04	0.37896E 04	RECTANGLE, SURFACE C, A/E =.41/.48
0.12550E 04	0.33833E 04	
0.15099E 04	0.27482E 04	
0.17649E 04	0.19278E 04	
0.20199E 04	0.97977E 03	
0.22748E 04	0.15698E 03	
0.25298E 04	0.38715E 01	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

9

		PLANETSHINE, TOTAL ABSORBED
0.10000E 04	0.45247E 03	RECTANGLE, SURFACE C, A/E =.41/.48
0.12550E 04	0.45247E 03	
0.15099E 04	0.45247E 03	
0.17649E 04	0.45247E 03	
0.20199E 04	0.45247E 03	
0.22748E 04	0.45247E 03	
0.25298E 04	0.45247E 03	
0.26972E 04	0.45247E 03	
0.26972E 04	0.45247E 03	
0.27848E 04	0.45247E 03	
0.30397E 04	0.45247E 03	
0.32947E 04	0.45247E 03	
0.35497E 04	0.45247E 03	
0.38046E 04	0.45247E 03	
0.40596E 04	0.45247E 03	

10

		SOLAR, TOTAL ABSORBED
0.10000E 04	0.27041E 03	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.32371E 03	
0.15099E 04	0.35251E 03	
0.17649E 04	0.55900E 03	
0.20199E 04	0.71280E 03	
0.22748E 04	0.70503E 03	
0.25298E 04	0.61813E 03	
0.26972E 04	0.46181E 03	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

11

		ALBEDO, TOTAL ABSORBED
0.10000E 04	0.60052E 03	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.53916E 03	
0.15099E 04	0.43921E 03	
0.17649E 04	0.30749E 03	
0.20199E 04	0.15418E 03	
0.22748E 04	0.25072E 02	
0.25298E 04	0.60272E 00	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

12

		PLANETSHINE, TOTAL ABSORBED
0.10000E 04	0.59397E 02	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.59397E 02	
0.15099E 04	0.59397E 02	
0.17649E 04	0.59397E 02	
0.20199E 04	0.59397E 02	
0.22748E 04	0.59397E 02	
0.25298E 04	0.59397E 02	
0.26972E 04	0.59397E 02	
0.26972E 04	0.59397E 02	
0.27848E 04	0.59397E 02	
0.30397E 04	0.59397E 02	
0.32947E 04	0.59397E 02	
0.35497E 04	0.59397E 02	
0.38046E 04	0.59397E 02	
0.40596E 04	0.59397E 02	

13

		SOLAR, TOTAL ABSORBED
0.10000E 04	0.99390E 02	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.13861E 03	
0.15099E 04	0.22796E 03	
0.17649E 04	0.52119E 03	
0.20199E 04	0.76718E 03	
0.22748E 04	0.83440E 03	
0.25298E 04	0.75985E 03	
0.26972E 04	0.60752E 03	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

14

		ALBEDO, TOTAL ABSORBED
0.10000E 04	0.72107E 03	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.64750E 03	
0.15099E 04	0.52754E 03	
0.17649E 04	0.36937E 03	
0.20199E 04	0.18505E 03	
0.22748E 04	0.28942E 02	
0.25298E 04	0.67615E 00	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

15

		PLANETSHINE, TOTAL ABSORBED
0.10000E 04	0.70624E 02	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.70624E 02	
0.15099E 04	0.70624E 02	
0.17649E 04	0.70624E 02	
0.20199E 04	0.70624E 02	
0.22748E 04	0.70624E 02	
0.25298E 04	0.70624E 02	
0.26972E 04	0.70624E 02	
0.26972E 04	0.70624E 02	
0.27848E 04	0.70624E 02	
0.30397E 04	0.70624E 02	
0.32947E 04	0.70624E 02	
0.35497E 04	0.70624E 02	
0.38046E 04	0.70624E 02	
0.40596E 04	0.70624E 02	

1

		SOLAR, DIRECT INCIDENT
0.10000E 04	0.51334E 03	DISK, SURFACE A, A/E =.22/.06
0.12550E 04	0.58315E 03	
0.15099E 04	0.51200E 03	
0.17649E 04	0.34644E 03	
0.20199E 04	0.15741E 03	
0.22748E 04	0.	
0.25298E 04	0.	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

2

		ALBEDO, DIRECT INCIDENT
0.10000E 04	0.	DISK, SURFACE A, A/E =.22/.06
0.12550E 04	0.	
0.15099E 04	0.	
0.17649E 04	0.	
0.20199E 04	0.	
0.22748E 04	0.	
0.25298E 04	0.	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

3

		PLANETSHINE, DIRECT INCIDENT
0.10000E 04	0.	DISK, SURFACE A, A/E =.22/.06
0.12550E 04	0.	
0.15099E 04	0.	
0.17649E 04	0.	
0.20199E 04	0.	
0.22748E 04	0.	
0.25298E 04	0.	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

4 /

SOLAR, DIRECT INCIDENT
TRAPAZOID, SURFACE B, A/E =.28/.86

0.10000E 04	0.11587E 03
0.12550E 04	0.22333E 03
0.15099E 04	0.57517E 03
0.17649E 04	0.76944E 03
0.20199E 04	0.82693E 03
0.22748E 04	0.84032E 03
0.25298E 04	0.80922E 03
0.26972E 04	0.76514E 03
0.26972E 04	0.
0.27848E 04	0.
0.30397E 04	0.
0.32947E 04	0.
0.35497E 04	0.
0.38046E 04	0.
0.40596E 04	0.

5

ALBEDO, DIRECT INCIDENT
TRAPAZOID, SURFACE B, A/E =.28/.86

0.10000E 04	0.47777E 02
0.12550E 04	0.44184E 02
0.15099E 04	0.37580E 02
0.17649E 04	0.28414E 02
0.20199E 04	0.17320E 02
0.22748E 04	0.53778E 01
0.25298E 04	0.21747E-00
0.26972E 04	0.
0.26972E 04	0.
0.27848E 04	0.
0.30397E 04	0.
0.32947E 04	0.
0.35497E 04	0.
0.38046E 04	0.
0.40596E 04	0.

6

PLANETSHINE, DIRECT INCIDENT
TRAPAZOID, SURFACE B, A/E =.28/.86

0.10000E 04	0.47590E 01
0.12550E 04	0.47590E 01
0.15099E 04	0.47590E 01
0.17649E 04	0.47590E 01
0.20199E 04	0.47590E 01
0.22748E 04	0.47590E 01
0.25298E 04	0.47590E 01
0.26972E 04	0.47590E 01
0.26972E 04	0.47590E 01
0.27848E 04	0.47590E 01
0.30397E 04	0.47590E 01
0.32947E 04	0.47590E 01
0.35497E 04	0.47590E 01
0.38046E 04	0.47590E 01
0.40596E 04	0.47590E 01

7

0.10000E 04	0.	SOLAR, DIRECT INCIDENT RECTANGLE, SURFACE C, A/E =.41/.48
0.12550E 04	0.	
0.15099E 04	0.	
0.17649E 04	0.84692E 02	
0.20199E 04	0.27714E 03	
0.22748E 04	0.45365E 03	
0.25298E 04	0.60778E 03	
0.26972E 04	0.69100E 03	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

8

0.10000E 04	0.38460E 03	ALBEDO, DIRECT INCIDENT RECTANGLE, SURFACE C, A/E =.41/.48
0.12550E 04	0.34335E 03	
0.15099E 04	0.27890E 03	
0.17649E 04	0.19564E 03	
0.20199E 04	0.99428E 02	
0.22748E 04	0.15927E 02	
0.25298E 04	0.39270E-00	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

9

0.10000E 04	0.39210E 02	PLANETSHINE, DIRECT INCIDENT RECTANGLE, SURFACE C, A/E =.41/.48
0.12550E 04	0.39210E 02	
0.15099E 04	0.39210E 02	
0.17649E 04	0.39210E 02	
0.20199E 04	0.39210E 02	
0.22748E 04	0.39210E 02	
0.25298E 04	0.39210E 02	
0.26972E 04	0.39210E 02	
0.26972E 04	0.39210E 02	
0.27848E 04	0.39210E 02	
0.30397E 04	0.39210E 02	
0.32947E 04	0.39210E 02	
0.35497E 04	0.39210E 02	
0.38046E 04	0.39210E 02	
0.40596E 04	0.39210E 02	

10

SOLAR, DIRECT INCIDENT
RECTANGLES, SURFACE D, .94,.90,.85

0.10000E 04	0.
0.12550E 04	0.
0.15099E 04	0.
0.17649E 04	0.37714E 02
0.20199E 04	0.70358E 02
0.22748E 04	0.76774E 02
0.25298E 04	0.60472E 02
0.26972E 04	0.35230E 02
0.26972E 04	0.
0.27848E 04	0.
0.30397E 04	0.
0.32947E 04	0.
0.35497E 04	0.
0.38046E 04	0.
0.40596E 04	0.

11

ALBEDO, DIRECT INCIDENT
RECTANGLES, SURFACE D, .94,.90,.85

0.10000E 04	0.88440E 02
0.12550E 04	0.79412E 02
0.15099E 04	0.64664E 02
0.17649E 04	0.45202E 02
0.20199E 04	0.22547E 02
0.22748E 04	0.35997E 01
0.25298E 04	0.83817E-01
0.26972E 04	0.
0.26972E 04	0.
0.27848E 04	0.
0.30397E 04	0.
0.32947E 04	0.
0.35497E 04	0.
0.38046E 04	0.
0.40596E 04	0.

12

PLANETSHINE, DIRECT INCIDENT
RECTANGLES, SURFACE D, .94,.90,.85

0.10000E 04	0.94890E 01
0.12550E 04	0.94890E 01
0.15099E 04	0.94890E 01
0.17649E 04	0.94890E 01
0.20199E 04	0.94890E 01
0.22748E 04	0.94890E 01
0.25298E 04	0.94890E 01
0.26972E 04	0.94890E 01
0.26972E 04	0.94890E 01
0.27848E 04	0.94890E 01
0.30397E 04	0.94890E 01
0.32947E 04	0.94890E 01
0.35497E 04	0.94890E 01
0.38046E 04	0.94890E 01
0.40596E 04	0.94890E 01

13

		SOLAR, DIRECT INCIDENT
0.10000E 04	0.	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.	
0.15099E 04	0.	
0.17649E 04	0.37714E 02	
0.20199E 04	0.70358E 02	
0.22748E 04	0.76774E 02	
0.25298E 04	0.60472E 02	
0.26972E 04	0.35230E 02	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

14

		ALBEDO, DIRECT INCIDENT
0.10000E 04	0.10152E 03	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.91187E 02	
0.15099E 04	0.74255E 02	
0.17649E 04	0.51885E 02	
0.20199E 04	0.25803E 02	
0.22748E 04	0.39031E 01	
0.25298E 04	0.86337E-01	
0.26972E 04	0.	
0.26972E 04	0.	
0.27848E 04	0.	
0.30397E 04	0.	
0.32947E 04	0.	
0.35497E 04	0.	
0.38046E 04	0.	
0.40596E 04	0.	

15

		PLANETSHINE, DIRECT INCIDENT
0.10000E 04	0.10932E 02	RECTANGLES, SURFACE D, .94,.90,.85
0.12550E 04	0.10932E 02	
0.15099E 04	0.10932E 02	
0.17649E 04	0.10932E 02	
0.20199E 04	0.10932E 02	
0.22748E 04	0.10932E 02	
0.25298E 04	0.10932E 02	
0.26972E 04	0.10932E 02	
0.26972E 04	0.10932E 02	
0.27848E 04	0.10932E 02	
0.30397E 04	0.10932E 02	
0.32947E 04	0.10932E 02	
0.35497E 04	0.10932E 02	
0.38046E 04	0.10932E 02	
0.40596E 04	0.10932E 02	

Appendix D
PROGRAM ERROR ANALYSIS

D.1 RECOMMENDATIONS OF SATELLITE SURFACE NODE AND ELEMENT SIZE

Each satellite surface can be divided into nodes by inputting $NV\beta$ and $NV\gamma$ as outlined in Appendix B.1. Variation of this input will result in more than one set of heat fluxes for a given surface. For example, note the difference in heat fluxes on surface D in the restart problem case shown in Appendix C.2. This difference, for identical node areas and surface properties, is due to the different effects in shading of these nodes. The computer program calculates the view factor for each element in each node. This is then averaged over the entire node; consequently, the total absorbed and direct incident heat fluxes are the node averages.

Each node is subdivided into elements which are treated as discrete areas, and represented by their area vectors. These are perpendicular to the surface of element at its center point. The view factor between each set of these area vectors is then calculated by the finite difference method. The accuracy of this method depends upon: (1) the area vector representation of a uniform distribution of the element's area around the center point of the element, and (2) the ratio of the magnitude of the area vector to the distance vector between centers.

The finite difference calculation of the view factor between node 1 and node 2 in Fig. D-1 can be written as

$$F_{1-2} = \frac{1}{A_1} \sum_{\substack{\text{Elements over} \\ \text{area } A_1}} \sum_{\substack{\text{Elements over} \\ \text{area } A_2}} \frac{\cos \phi_1 \cos \phi_2 \Delta A_1 \Delta A_2}{\pi r^2}$$

Therefore, the two basic requirements which dictate the size and number of elements for each node are: (1) the elements be fine enough to adequately describe the node for possible shading by other surfaces, and (2) the elements be fine enough so that the finite difference error is small. This finite difference error can be approximated for each element by:

$$\% \text{ error} = 100 \,(2 - \cos \theta_A - \cos \theta_B)$$

where θ_A and θ_B are the angles measured from the center line of the element to the element edges as shown in Fig. D-2.

To guide the program user in selecting the size and number of elements into which each node is to be divided, the view factors between two square rectangles have been calculated and plotted as shown in Fig. D-3 and Fig. D-4. However, it should be remembered that the geometric view factor is only one of three variables (area, emissivity or reflectivity, and view factor) used in the

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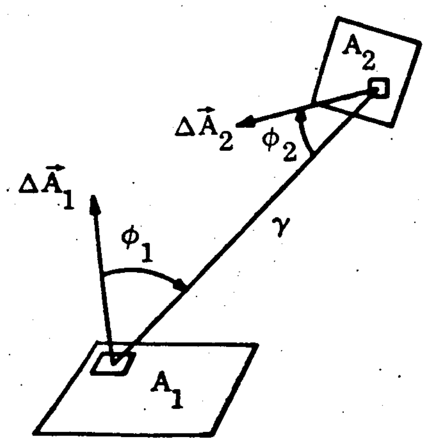

Fig. D-1 Geometric View Factor Notation

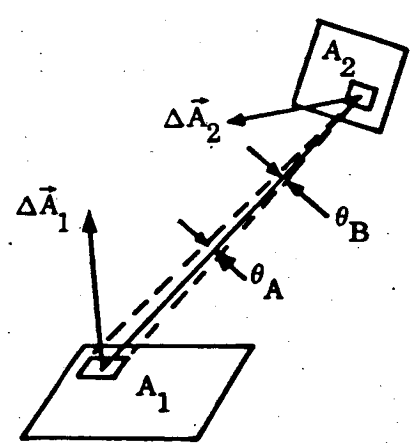

Fig. D-2 Error of Finite Difference Element

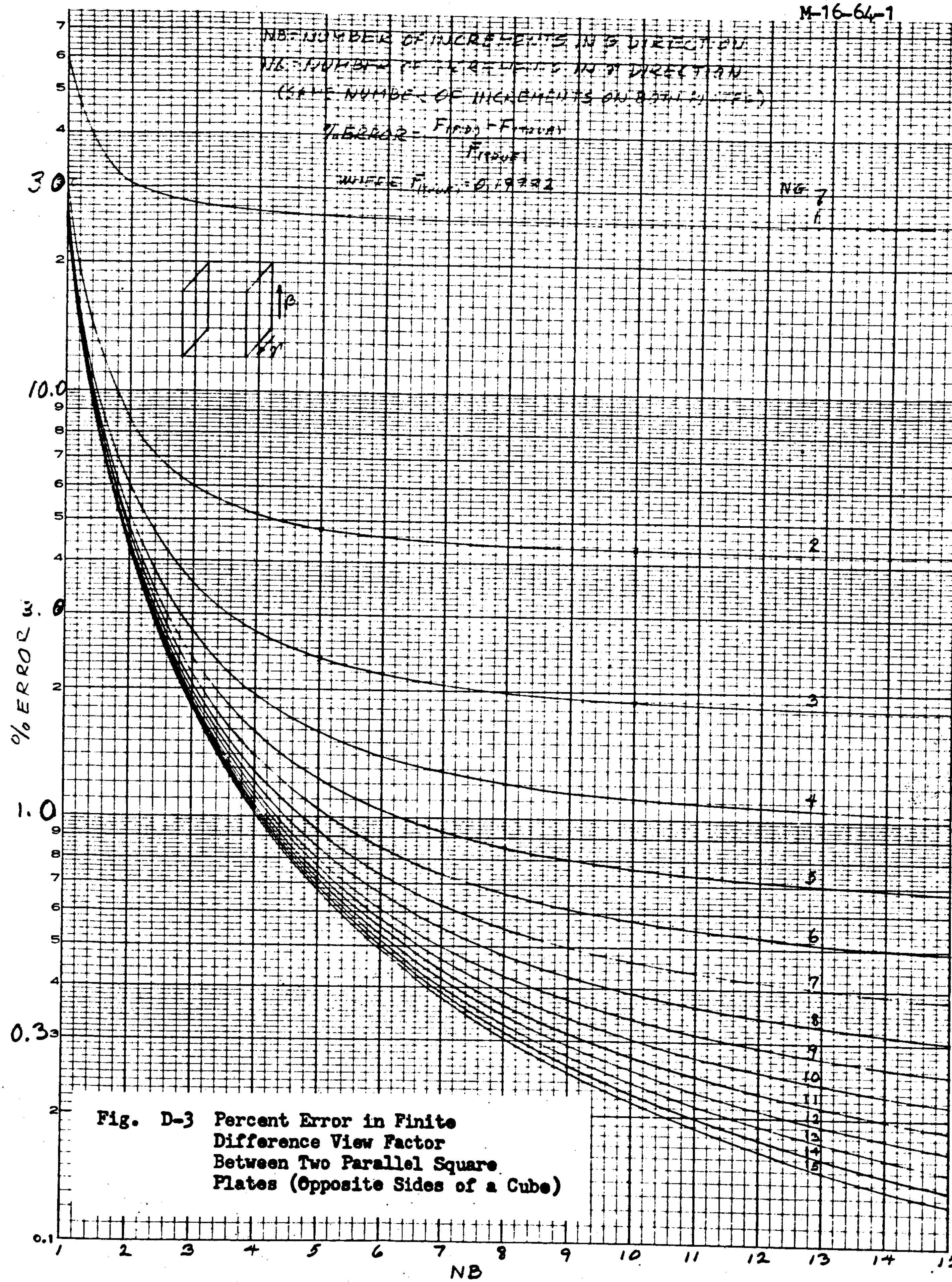

Fig. D-3 Percent Error in Finite Difference View Factor Between Two Parallel Square Plates (Opposite Sides of a Cube)

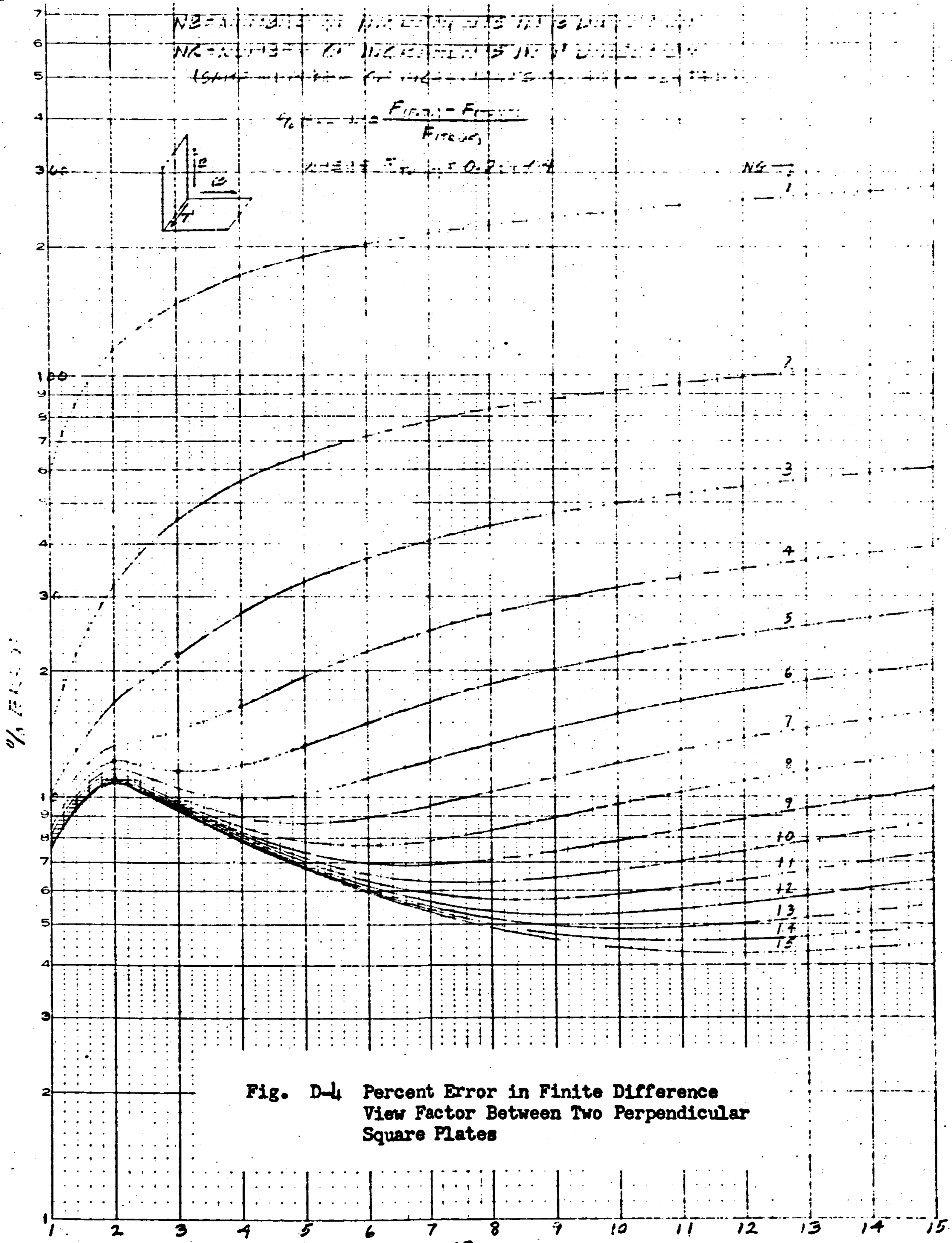

Fig. D-4 Percent Error in Finite Difference View Factor Between Two Perpendicular Square Plates solution of the radiant interchange equations (see Appendix A.2.6) and the view factor error should not be construed to be the equivalent heat flux error. This is discussed more at the end of Appendix D.2.

D.2 THE PLANET VIEW FACTOR ERROR

The finite difference method will cause an appreciable error in calculating the view factor between each satellite surface node and the planet if the planet is not divided into fine enough elements. The planet is divided into 3 nodes in the β direction and 12 nodes in the γ direction, which results in 36 nodes for the planet. Each of the planet nodes is divided into one element in the γ direction, but may be divided into as many as 8 elements in the β direction. The variable number of elements in the direction is calculated by a routine in subroutine VIEW depending upon the satellite altitude, and the percent of error that the program user inputs to the computer. This routine continues to increase the number of elements in the β direction until the view factor from an imaginary horizontal flat plate to the planet is less than the percent error input by the program user.

A plot of the percent error as function of the dimensionless ratio (satellite altitude/planet radius) for various $N\beta$ (elements in the β direction) is plotted in Fig. D-5. This graph indicates the general expected trend: the larger the number of $N\beta$ the

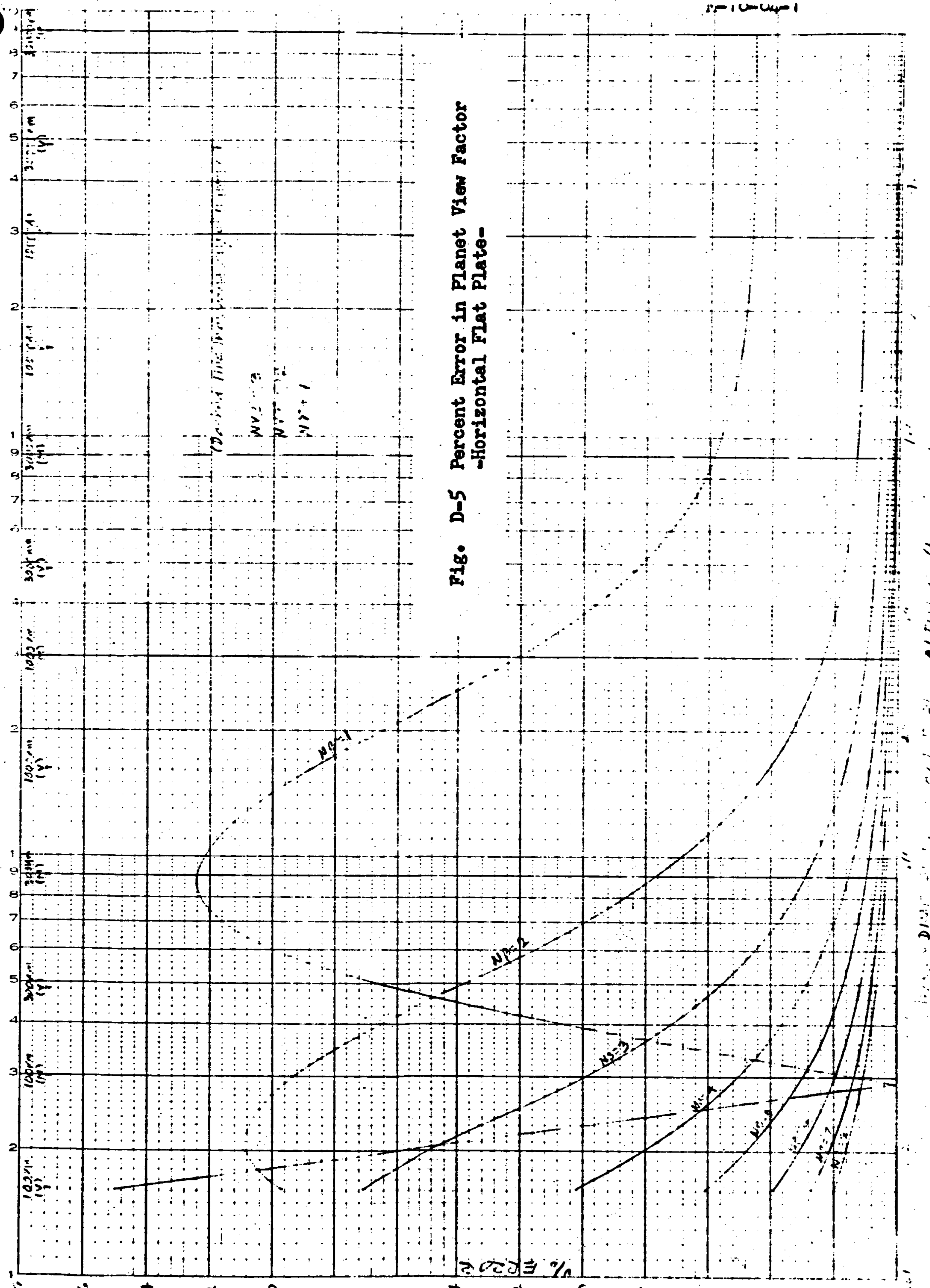

Fig. D-5 Percent Error in Planet View Factor -Horizontal Flat Plate-less the percent of error for any dimensionless ratio. However, the program user should note the negative error that occurs when $N\beta = 1$ and $h/R_p < .03$, which is due to the magnitude of the planet element area vectors in relation to their span vectors for those planet nodes closest to the satellite. Care should be taken when selecting the view factor error in this region because the computer checks the absolute magnitude of the calculated error starting with $N\beta = 1$.

The computer routine will continue to increase $N\beta$ until the error shown on Fig. D-5 is less than the error selected by the program user. As an example, if the percent error is input as 5 percent, and the h/R_p ratio was never less than 0.1, then $N\beta$ would be 3, and the total number of planet elements would be 36 x 3 = 108. With this information, the maximum number of satellite elements can be calculated as 1000 - 108 - 1 = 891 where the extra 1 is for the sun element.

The satellite node view factor to the planet is different if the node is not horizontal and the percent view factor error is also different. A vertical plate is shown in Fig. D-6 with the same variables plotted as in Fig. D-5. The computer routine divides the planet nodes into the elements as shown in Fig. D-5, which will result in the error shown in Fig. D-6 for a vertical plate.

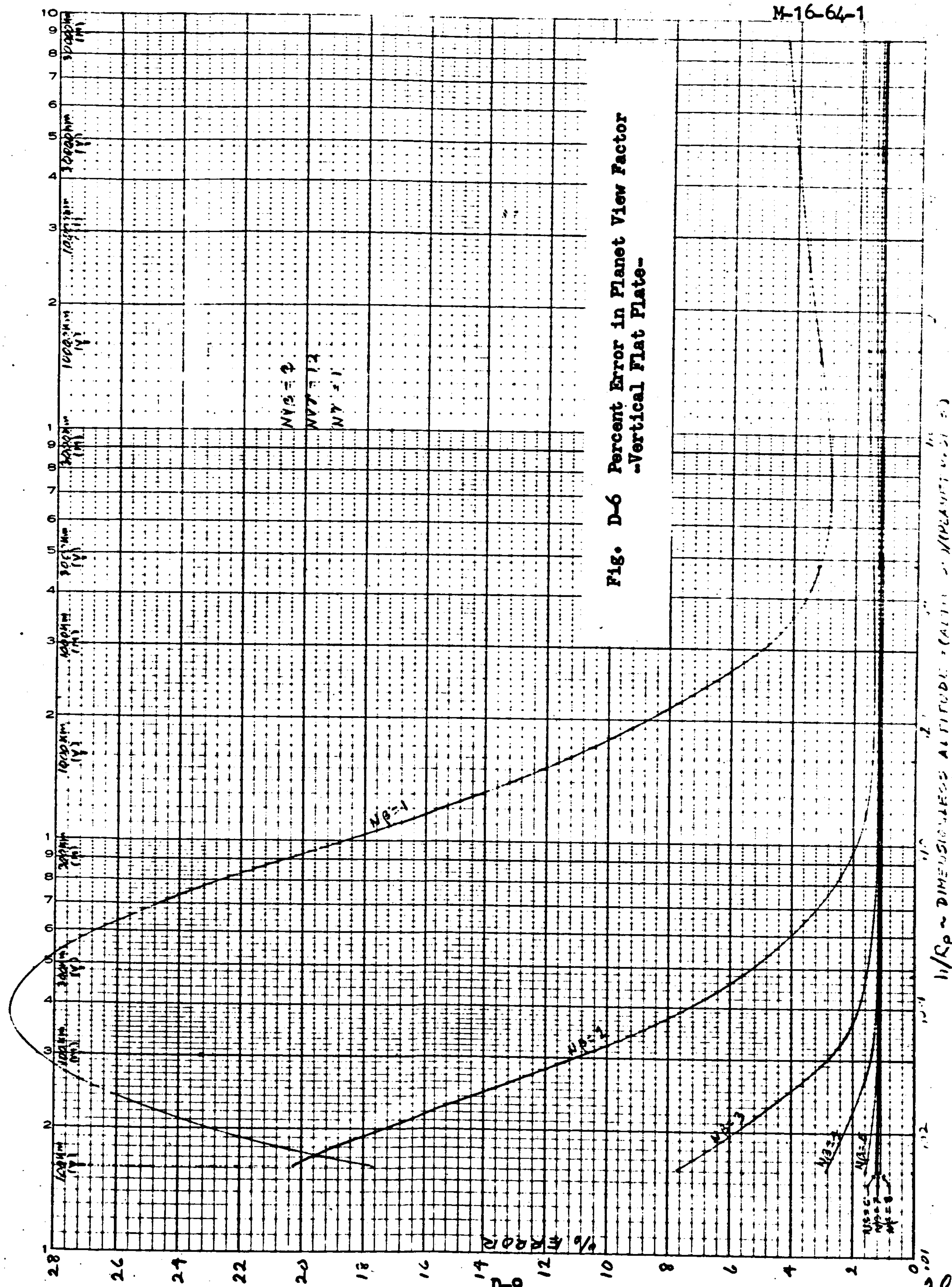

Fig. D-6 Percent Error in Planet View Factor -Vertical Flat Plate-

The radiation constant equations which are solved from their matrix form (Appendix A.2.6) for the radiation constant between two bodies are written in terms of the areas, the emissivities, and the geometric view factors for these bodies. If an error analysis is performed with these equations, the following equations will result which can be solved for the heat flux error due to a view factor error.

$$\delta \beta_{1x} / _{G_{12}} = \left(\rho_1 \frac{\rho_2 F_{12} F_{21}}{1 - \rho_1 \rho_2 F_{12} F_{21}} + \left[\frac{\beta_{2x} \ \epsilon_1}{\beta_{1x} \ \epsilon_2} \right] \rho_2 \frac{F_{21}}{1 - \rho_1 \rho_2 F_{12} F_{21}} \right) \delta$$

$$\delta \beta_{1x} / _{G_{1x}} = \frac{G_{1x} \ \epsilon_1}{\beta_{1x} (1 - \rho_1 \rho_2 F_{12} F_{21})} \delta G_{1x}$$

where:

$\delta \beta_{1x} / _{G_{12}}$ = fraction of the heat flux error to node 1 due to the error in the view factor between the two satellite surface nodes, and

$\delta \beta_{1x} / _{G_{1x}}$ = fraction of the heat flux error to node 1 due to the error in the view factor between the satellite surface, node 1, and the entire planet, x.

β_{2x} $= \mathcal{F}_{2x} A_2$

$$G_{12} = F_{12} A_2$$

The above equations are for two satellite nodes, 1 and 2, and a source node, x, which could be the sun or the mean planet node.

Examples:

(1) For δG_{12} of 20 percent, i.e., $F_{12} A_1 = .2$ actual, where the finite difference calculation gives 0.24, the resulting heat flux change is 0.84 percent for the following conditions:

$$\varepsilon_1 = \varepsilon_2 = .8$$

$$A_1 = A_2 = 1$$

$$G_{2x} = G_{1x}$$

(2) For $\delta G_{1x} = 20$ percent, the resulting heat flux error is 10.6 percent for one satellite node horizontal to the earth's surface at 200 sm with

$$\varepsilon_1 = .8$$

$$A_1 = 1$$

$G_{1x} = .9$

(3) For (2), the same condition, except at 610 sm, would give only a 7.6 percent heat flux error where $G_{1x} = .75$.

(4) For $\delta G_{1x} = 20$ percent, the resulting heat flux error is 1.42 percent for one satellite node perpendicular to the earth's surface at 200 sm with

$$\epsilon_1 = .8 \qquad A_1 = 1 \qquad G_{1x} = .31$$

(5) For (4), the same conditions, except at 610 sm, would give only 0.61 percent heat flux error where $G_{1x} = .2$.

D.3 ESTIMATED COMPUTER RUN TIME

The computer run time is a function of:

- Total number of elements
- Total number of points in orbit to be calculated
- Satellite orbit and orientation

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- Shading of satellite surfaces.

These four variables can be grouped to give the following estimates:

1. Circular Orbit, planet-oriented satellite

   - With shading

     $$\text{Min.} = K_1 C_1 P N^2 + C_3$$

   - With no shading

     $$\text{Min.} = C_1 P N^2 + C_3$$

2. Elliptical Orbit, planet-or space-oriented satellite

   - With shading

     $$\text{Min.} = K_2 C_2 P N^2 + C_3$$

   - With no shading

     $$\text{Min.} = C_2 P N^2 + C_3$$

where:

P = total number of points in orbit to be calculated

N = total number of elements

$C_1 = 6.6 \times 10^{-7}$

$C_2 = 2.4 \times 10^{-6}$

$C_3 = .28$

$K_1 = 2.0$

$K_2 = 2.5$

Appendix E
PROGRAM LISTINGS

The listings in this appendix are of all the source decks used in the generalized heat flux computer program, also the closed (or library) functions of the trigonometric functions in degrees. The program calls many open (or built-in) functions and the SQRTF closed function in addition to the trigonometric functions.

```
      FORTRAN
C     MAIN PROGRAM OF THE GENERALIZED HEAT FLUX STUDY
      DIMENSION DATA(22,16),LDATA(22,16),DM1(9343),AS(22),AA(22),E(22),
     1DM2(201),DM3(61),IN(2),TIME(40),DM4(5241),WRIT(22,6),DM5(441)
      DIMENSION R(3,3)
      COMMON DATA,DM1,AS,AA,E,DM2,NS,SHD,NITE,IZ,IK,DM3,RAD,PI,DCR,
     1 RPLAN,IN,TIME,DM4,WRIT,ECC,PERIOD,NPO,NTABLE,SBC,TSUN,TSS,TDS
     2,DM5,THE,BETA,KAD,DSUN
      EQUIVALENCE (DATA,LDATA)
      PI = 3.1415927
      DCR = PI/180.
1     FORMAT(I5,5X6E10.5 )
2     FORMAT(39H1  ERROR IN BLOCK IDENTIFICATION NUMBER )
3     FORMAT(4XA6,5E10.5)
4     FORMAT( / I5,18H  PLANET DATA FOR A6, E16.5/
     1 9X24HGRAVITATIONAL CONSTANT =E12.5,9X27HSTEPHAN-BOLTZMAN CONSTANT
     2 =E12.5/9X24HPLANET DISTANCE TO SUN =E12.5,9X27HDARK SIDE TEMPERAT
     3URE      =E12.5 /9X24HPLANET ALBEDO, PERCENT =E12.5, 9X27HSUB-SOLAR
     4 TEMPERATURE      =E12.5 /9X24HPLANET RADIUS           =E12.5,9X27HS
     5OLAR TEMPERATURE          =E12.5 /9X24HSUN RADIUS              =
     6 E12.5,9X27HDELTA ANGLE                 =E12.5 )
5     FORMAT(10X5E10.5 )
6     FORMAT(/I5,17H  SATELLITE ORBIT 11XE12.5        /9X24HINITIAL THET
     1A ANGLE     =E12.5,9X27HNUMBER OF DELTA THETA'S    =I4/9X24HFINAL TH
     2ETA ANGLE       =E12.5,9X27HALTITUDE OF PERIAPSIS      =E12.5/
     3 9X24HINCLINATION ANGLE      =E12.5,9X27HALTITUDE OF APOAPSIS
     4 =E12.5/9X24HOMEGA ANGLE          =E12.5,9X27HINITIAL TIME
     5          =E12.5 /9X24HALPHA(P) ANGLE          =E12.5)
7     FORMAT(/I5,23H  SATELLITE ORIENTATION /9X15HINITIAL PHI    =F6.1,
     1 7X31HORIENTATION( 1=PLANET,2=SPACE)=I3/9X15HINITIAL PSI    =F6.1/
     2 9X15HINITIAL OMEGA =F6.1 /)
8     FORMAT(/I5,20H  SATELLITE SURFACES 5X20HNUMBER OF SURFACES =I3,
     118H   PERCENT ERROR =F5.1,34H   SURFACE SHADING(-1=NO, 1=YES) =
     2 F4.0   )
9     FORMAT(5I5,5A6,A4/ 5E10.5 /5XF5.3,5XF5.3,3E10.5 /5XF5.3,10X3E10.5)
10    FORMAT(6X5I5,5A6,A4 /7X5E14.5 / 16XF5.3,9XF5.3,3E14.5 /16XF5.3,
     1 14X3E14.5 )
11    FORMAT(/I5,31H  OUTPUT VARIABLES      TABLES =I3,11H   FORMAT =I3,
     1 10H   CARDS =I3,14H   VARIABLES =I3 )
12    FORMAT(13A6,A2)
13    FORMAT(20H1  ERROR IN BLOCK 5    )
14    FORMAT(39H1 ERROR IN BLOCK 3, VEHICLE ORIENTATION )
      WRITE OUTPUT TAPE 6,405
      READ INPUT TAPE 5,12,(AS(I), I =1,14)
      WRITE OUTPUT TAPE 6,12,(AS(I), I =1,14)
15    READ INPUT TAPE 5,1,ID,DIST,A,B,C,D,F
      IF(ID -5)18,18,19
18    GO TO (20,30,40,44,49),ID
19    WRITE OUTPUT TAPE 6,2
      CALL EXIT
20    READ INPUT TAPE 5,3,PID,SBC,TDS,TSS,TSUN,DELTA
      IF(DIST)21,21,22
21    DIST = 1.0
22    WRITE OUTPUT TAPE 6,4,ID,PID,DIST,A,SBC,B,TDS,C,TSS,D,TSUN,F,DELTA
      GC = A
```

```
      DSUN = B*DIST
      AS(2) = 1.0 - C/100.
      RPLAN = D*DIST
      RSUN = F*DIST
C     SUN DESCRIPTION IS DATA(1,K)
      LDATA(1,1) = -2
      DO 26 I=2,5
   26 LDATA(1,I) = 1
      DATA(1,6) =DSUN
      LDATA(1,7) = 0
      LDATA(1,8) = 0
      DATA(1,9) =RSUN
      DATA(1,10) = 360.
      LDATA(1,11)= 0
      LDATA(1,12)= 0
      LDATA(1,13)= 0
C     PLANET DESCRIPTION IS DATA(2,K)
      LDATA(2,1) = 6
      LDATA(2,2) = 1
      LDATA(2,3) = 1
      LDATA(2,4) = 3
      LDATA(2,5) = 12
      DATA(2,6) = RPLAN
      LDATA(2,7)= 0
      LDATA(2,8)= 0
      DATA(2,10)= 360.
      GO TO 15
   30 READ INPUT TAPE 5,5,ALPHA,PHO,RP,RA,TIMEI
      IF(DIST)31,31,32
   31 DIST =1.0
   32 NPOA= PHO +.0001
      WRITE OUTPUT TAPE 6,6,ID,DIST,A,NPOA,B,RP,C,RA,D,TIMEI,ALPHA
      THETIN = A
      THETFI = B
      AINC = C
      OMEGA = D
      RP = RP*DIST
      RA = RA*DIST
      BETA = ASINF(SINF(C)*SINF(D)) -ASINF(COSF(C)*TANF(DELTA))
      THE = ALPHA + ATANF(COSF(C)*TANF(D)) + ATANF(TANF(DELTA)*COSF(ASI
     1NF(COSF(C)/COSF(DELTA))))
      IF(D -90.)36,36,33
   33 IF(D -270.)34,34,36
   34 THE = THE +180.
   36 IF(THE -360.)15,15,37
   37 THE =THE -360.
      GO TO 15
   40 IORT = C + .0001
      WRITE OUTPUT TAPE 6,7,ID,DIST,IORT,A,B
      IF(IORT -2)42,42,41
   41 WRITE OUTPUT TAPE 6,14
      CALL EXIT
   42 C1 = COSF(DIST)
      C2 = COSF(A)
      C3 = COSF(B)
```

```
      S1 = SINF(DIST)
      S2 = SINF(A)
      S3 = SINF(B)
      R(1,1) = C2*C1
      R(2,1) = -C2*S1
      R(3,1) = S2
      R(1,2) = -S3*S2*C1 + C3*S1
      R(2,2) = S3*S2*S1 + C3*C1
      R(3,2) = S3*C2
      R(1,3) = -C3*S2*C1 - S3*S1
      R(2,3) =  C3*S2*S1 - S3*C1
      R(3,3) = C3*C2
      GO TO 15
44    NS = DIST + 2.00001
      I = DIST + .0001
      WRITE OUTPUT TAPE 6,8,ID,I,A,B
      ERR =A
      SHD =B
      K = 1
      DO 48 I =3,NS
      READ INPUT TAPE 5,9,  (DATA(I,J), J=1,5),(WRIT( K ,J),J=1,6),
     1 (DATA(I,J), J=6,10), AS(I), AA(I), (DATA(I,J), J =11,13), E(I),
     2 (DATA(I,J), J=14,16)
      WRITE OUTPUT TAPE 6,10, (DATA(I,J), J=1,5),(WRIT( K ,J),J=1,6),
     1 (DATA(I,J), J=6,10), AS(I), AA(I), (DATA(I,J), J =11,13), E(I),
     2 (DATA(I,J), J=14,16)
      KK = LDATA(I,4)*LDATA(I,5)
      IF(KK)45,45,46
45    KK =1
46    KK = KK +K -1
      DO 47 JJ =K,KK
      DO 47 J =1,6
47    WRIT(JJ,J) = WRIT(K,J)
48    K =KK +1
      GO TO 15
49    NTABLE =DIST +.0001
      NPO = NPOA
      NFORMT =A   +0.0001
      NCARDS = B +0.0001
      NVAR  = C +.0001
      WRITE OUTPUT TAPE 6,11,ID,NTABLE,NFORMT,NCARDS,NVAR
      IF(NTABLE -2)51,51,50
50    WRITE OUTPUT TAPE 6,13
      CALL EXIT
51    A =(RA +RP +2.0*RPLAN)/ 2.0
      ECC =       (RA -RP)/A*0.5
      PERIOD = 2.0*PI*SQRTF(A/RPLAN*A/RPLAN*A/GC)
      IF(THETIN -THETFI)54,55,52
52    WRITE OUTPUT TAPE 6,53
53    FORMAT(59H1  ERROR IN BLOCK 2, THETA FINAL IS LESS THAN THETA INI
     1TIAL )
      CALL EXIT
54    DEG = (THETFI -THETIN)/FLOATF(NPO)
      KAD = 1
      GO TO 57
```


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```
55    DEG = 360./FLOATF(NPO)
      KAD = -1
57    ANGLE = THETIN -DEG
      IF(ECC)60,64,62
60    WRITE OUTPUT TAPE 6,61
61    FORMAT(51H1 ERROR IN BLOCK 2, PERIAPSIS GREATER THAN APOAPSIS )
      CALL EXIT
62    RDD = A*(1.0 -ECC**2)
      RAD = RDD/(1.0 + ECC*COSF(THETIN))
      EG = ACOSF((A -RAD)/A/ECC)
      TIMEP = PERIOD/2.0*(EG*DCR -ECC*SINF( EG))/PI
      GO TO 80
64    ENGLE =THETIN
      IF(ENGLE -180.)70,70,71
70    TIMEP = PERIOD*ENGLE/360.
      GO TO 72
71    TIMEP = PERIOD*(.5 -(ENGLE -180.))/360.
72    RAD = RA + RPLAN
80    ANN = THETIN -180.
      IF(ANN)86,86,85
85    TIMEP = -TIMEP
86    CALL SHADOW (RP,TS1,TS2)
      IF(TS1 -400.)92,90,92
90    NUS =1
      GO TO 115
92    NUS =-1
      TOT = THE + THETIN
      IF(TOT -360.)98,98,95
95    TOT = TOT -360.
98    IF(TS1 -TOT)100,115,115
100   IF(TS2 -TOT)115,115,112
112   KIST =-1
      MAN = -1
      GO TO 116
115   KIST =1
      MAN = 1
116   IN(1) = 0
      IN(2) = 0
      IZ = 1
      I = 0
      MUM =0
120   I =I + 1
      ANGLE = ANGLE +DEG
      IF(NUS)127,142,142
127   TOT = THE + ANGLE
      DO 135 J =1,3
      IF(TOT -360.)136,136,130
130   TOT = TOT -360.
135   CONTINUE
136   IF(TS1 -TOT)138,142,142
138   IF(TS2 -TOT)142,142,140
140   KISS =-1
      NITE = 1
      GO TO 145
142   KISS = 1
```

```
      NITE = -1
  145 IF(KISS -KIST)146,149,146
  146 MUM = MUM +1
      IF(MUM -2)280,280,400
  149 IF(I -NPO)150,150,157
  150 IF(I-1)151,151,160
  151 IF(KAD)155,155,156
  155 TIME(1) = 0.
      GO TO 212
  156 TIME(1) =TIMEI
      GO TO 212
  157 IF(KAD)400,400,158
  158 IF(I-NPO-1)160,160,400
  160 IF(ECC)161,161,180
  161 ENGLE =ANGLE
      DO 166 J=1,4
      IF(ENGLE -180.)170,170,165
  165 ENGLE =ENGLE -180.
  166 CONTINUE
  170 GO TO (172,174,172,174),J
  172 TIME(I)= PERIOD*ENGLE/360.
      GO TO 183
  174 TIME(I)= PERIOD*(180. -ENGLE)/360.
      GO TO 183
  180 RAD = RDD/(1.0 +ECC*COSF(ANGLE))
      EG = ACOSF((A -RAD)/A/ECC)
      TIME(I) =PERIOD/2.0*(EG*DCR -ECC*SINF(EG))/PI
  183 IF(ANN)185,185,189
  185 IF(ANGLE -180.)187,187,194
  187 TIME(I) =TIME(I) -TIMEP
      GO TO 199
  189 IF(ANGLE -360.)190,190,192
  190 TIME(I) = -TIME(I) -TIMEP
      GO TO 199
  192 IF(ANGLE -540.)187,187,196
  194 IF(ANGLE -360.)196,196,198
  196 TIME(I) = PERIOD -TIMEP -TIME(I)
      GO TO 199
  198 TIME(I) = PERIOD +TIME(I) -TIMEP
  199 IF(KAD)212,212,210
  210 TIME(I) = TIME(I) + TIMEI
  212 GO TO (220,230),IORT
C     PLANET ORIENTED
  220 DING = SINF(TOT)*COSF(BETA)
      BING = COSF(TOT)*COSF(BETA)
      SB = SINF(BETA)
      RSX = -R(1,1)*DING +R(2,1)*SB +R(3,1)*BING
      RSY = -R(1,2)*DING +R(2,2)*SB +R(3,2)*BING
      RSZ = -R(1,3)*DING +R(2,3)*SB +R(3,3)*BING
      IF(IZ)224,222,224
  222 IF(ECC)224,223,224
  223 IK = 0
      GO TO 240
  224 IK = 1
      RPX = R(3,1)
```

```
      RPY = R(3,2)
      RPZ = R(3,3)
      GO TO 240
C     SUN DIRECTED
  230 SB = ANGLE +ALPHA
      TOTAL = OMEGA + ATANF(COSF(AINC)*TANF(SB))
  231 IF(SB -90.)238,238,232
  232 IF(SB -270.)233,233,234
  233 TOTAL = TOTAL +180.
      GO TO 238
  234 IF(SB -360.)235,235,236
  235 TOTAL = TOTAL +360.
      GO TO 238
  236 SB = SB -360.
      GO TO 231
  238 SIG = ASINF(SINF(AINC)*SINF(SB))
      DING = SINF(TOTAL)*COSF(SIG)
      BING = COSF(TOTAL)*COSF(SIG)
      SS = SINF(SIG)
      RPX = R(1,1)*SS -R(2,1)*DING + R(3,1)*BING
      RPY = R(1,2)*SS -R(2,2)*DING + R(3,2)*BING
      RPZ = R(1,3)*SS -R(2,3)*DING + R(3,3)*BING
      IK = 1
      IF(IZ)239,255,239
  239 SD = SINF(DELTA)
      CD = COSF(DELTA)
      RSX = -R(1,1)*SD + R(3,1)*CD
      RSY = -R(1,2)*SD + R(3,2)*CD
      RSZ = -R(1,3)*SD + R(3,3)*CD
  240 HIP = SQRTF(RSX**2 +RSY**2)
      IF(RSX)243,245,242
  242 DATA(1,14) = ACOSF(RSY/HIP)
      GO TO 250
  243 DATA(1,14) = -ACOSF(RSY/HIP)
      GO TO 250
  245 IF(RSY)249,248,248
  248 LDATA(1,14) =0
      GO TO 250
  249 DATA(1,14) = 180.
  250 LDATA(1,15) = 0
      DATA(1,16) = -ACOSF(RSZ)
      IF(IK)255,270,255
  255 HIP = SQRTF(RPX**2 +RPY**2)
      IF(RPX)259,260,257
  257 DATA(2,14) = ACOSF(RPY/HIP)
      GO TO 265
  259 DATA(2,14) = -ACOSF(RPY/HIP)
      GO TO 265
  260 IF(RPY)264,262,262
  262 LDATA(2,14) =0
      GO TO 265
  264 DATA(2,14) =180.
  265 LDATA(2,15) =0
      DATA(2,16) = -ACOSF(RPZ)
      DATA(2,11) =-RAD*RPZ
```

```
      DATA(2,12) =-RAD*RPY
      DATA(2,13) =-RAD*RPX
  270 CALL VIEW(ERR)
      CALL FLUX
      IZ = 0
      IF(KISS -KIST)310,120,310
  280 N =I +1
      M =I +2
      TOTE = TOT
      AANGLE = ANGLE
      IF(KIST)285,285,282
  282 ANGLE =TS1 -THE
      TOT = TS1
      IN(1) = N
      GO TO 290
  285 ANGLE = TS2 -THE
      TOT = TS2
      IN(2) = I
  290 IF(ANGLE)295,298,298
  295 ANGLE = ANGLE + 360.
  298 IF(THETIN -ANGLE)302,302,300
  300 ANGLE = ANGLE +360.
  302 NITE =-1
      GO TO 160
  310 TOT =TOTE
      ANGLE =AANGLE
      TIME(N) = TIME(I)
      KIST = KISS
      NITE = -KISS
      I =M
      NPO = NPO +2
      GO TO 160
  400 IF(KAD)402,402,401
  401 NPO = NPO +1
  402 CALL OUTPUT (NVAR,NCARDS,NFORMT,MAN,THETIN,THETFI)
      WRITE OUTPUT TAPE 6,405
  405 FORMAT(1H1)
      GO TO 15
      END


*     FORTRAN
      SUBROUTINE SHADOW (RP,TS1,TS2)
      DIMENSION DM1(10031),DM2(5415),DM3(448)
      COMMON DM1,RO,DM2,E,DM3,THETP,BETA
      R1 = RO + RP
      CB = COSF(BETA)
      C1 = 1.
      THETA =90.
    1 DO 3 J =1,5
      C2 = (100.*C1)/10.**J
      DO 2 I =1,10
      THETA = THETA +C2
      CV = THETA -THETP
```


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      CDT = COSF(CV)
      EN = SQRTF(1.-((RO/R1)*((1.+E*CDT)/(1.+E)))**2)
      CTH = COSF(THETA)
      SZ = CB*CTH
      IF(SZ+EN)3,4,2
    2 CONTINUE
      GO TO 7
    3 THETA =THETA -C2
    4 IF(C1)6,6,5
    5 TS1 = THETA
      C1 = -1.
      THETA = 270.
      GO TO 1
    6 TS2 = THETA
      GO TO 8
    7 TS1 = 400.
      TS2 = 400.
    8 RETURN
      END


*     FORTRAN
      SUBROUTINE VIEW(ERR)
      DIMENSION DATA(22,16),LDATA(22,16),DM1(9409),P(22,3,3),R(3),
     1 DM2(2),A(3),NTN(57)
      COMMON DATA,DM1,P,R,NS,DM2,IZ,IK,A,NV,NTN,RAD,PI,DCR,RPLAN
      EQUIVALENCE (DATA,LDATA)
      IF(IZ)4,1,4
    1 NVV = NV
      IF(IK)2,3,2
    2 NSS = 2
      GO TO 5
    3 NSS =1
      GO TO 20
    4 NSS = NS
C     PLANET VIEW FACTOR ERROR
    5 RSQ =RPLAN**2
      RTQ = RAD**2
      FEA = RSQ/RTQ
      DATA(2,9) = ACOSF(RPLAN/RAD)
      NVB = LDATA(2,4)
      DO 10 I =1,7
      NBT = I*NVB
      DB = DATA(2,9)/FLOATF(NBT)
      DB1 = -DB/2.0
      FE1 = 0.
      DO 9 J =1,NBT
      BA = FLOATF(J)*DB + DB1
      RA =        RTQ +RSQ -2.0*RAD*RPLAN*COSF(BA)
      BTT = SINF(BA)
      BIT = BTT/SQRTF(RA)
    9 FE1 = FE1 + COSF(ASINF(RAD*BIT))*COSF(ASINF(RPLAN*BIT))*
     1 RSQ*BTT*DB*DCR*2.0/RA
      ERR1 = ABSF(FE1 -FEA)/FEA*100.
```

```
      IF(ERR1 -ERR)11,11,10
10    CONTINUE
11    LDATA(2,2) = I
20    N = 0
      NV = 0
      DO 50 J =1,NSS
      ILK = LDATA(J,1)
      NB = LDATA(J,2)
      NG = LDATA(J,3)
      NVB = LDATA(J,4)
      NVG = LDATA(J,5)
      A(1) = DATA(J,6)
      BE = DATA(J,7)
      GA = DATA(J,8)
      DB = DATA(J,9)
      DG = DATA(J,10)
      C1 = COSF(DATA(J,14))
      C2 = COSF(DATA(J,15))
      C3 = COSF(DATA(J,16))
      S1 = SINF(DATA(J,14))
      S2 = SINF(DATA(J,15))
      S3 = SINF(DATA(J,16))
      P(J,1,1) =C2*C1
      P(J,2,1) = -C2*S1
      P(J,3,1) = S2
      P(J,1,2) =-S3*S2*C1 +C3*S1
      P(J,2,2) = S3*S2*S1 + C3*C1
      P(J,3,2) = S3*C2
      P(J,1,3) =-C3*S2*C1 - S3*S1
      P(J,2,3) = C3*S2*S1 - S3*C1
      P(J,3,3) = C3*C2
      IF(IZ)22,35,22
22    IF(NB)24,24,25
24    NB = 1
25    IF(NG)26,26,27
26    NG = 1
27    IF(NVB)28,28,29
28    NVB =1
29    IF(NVG)30,30,31
30    NVG = 1
31    LDATA(J,2) = NB
      LDATA(J,3) = NG
      LDATA(J,4) = NVB
      LDATA(J,5) = NVG
35    DVB =(DB -BE)/FLOATF(NVB)
      DVG =(DG -GA)/FLOATF(NVG)
      DB = DVB/FLOATF(NB)
      DG = DVG/FLOATF(NG)
      A(2) = BE -.5*DB
      DO 50 JV =1,NVB
      A(3) = GA -.5*DG
      A(2) = A(2) + DVB
      DO 50 KV =1,NVG
      A(3) =A(3) +DVG
      A(2) =A(2) -DVB
```

```
      NV = NV + 1
      DO 49 KJ =1,NB
      A(3) = A(3) - DVG
      A(2) = A(2) +DB
      DO 49 KX =1,NG
      A(3) =A(3) + DG
      N = N + 1
      CALL VECTOR (ILK,DB,DG,N,J)
 49   CONTINUE
 50   NTN(NV) = N
      IF(IZ)70,70,54
 54   IF(N - 1000)58,58,56
 56   WRITE OUTPUT TAPE 6,57
 57   FORMAT(21H   TOO MANY ELEMENTS )
      CALL EXIT
 58   IF(NV -57)80,80,60
 60   WRITE OUTPUT TAPE 6,61
 61   FORMAT(17H   TOO MANY NODES)
      CALL EXIT
 70   NV = NVV
 80   CALL OMEGA
      RETURN
      END


*     FORTRAN
      SUBROUTINE VECTOR(ILK,DB,DG,N,J)
      DIMENSION DATA(22,16),LDATA(22,16),POS(1000,3),ARA(1000,3),DM1(34
     109),P(22,3,3),DM2(8),A(3),DM3(60),DM4(3)
      DIMENSION B(3),C(3)
      COMMON DATA,POS,ARA,DM1,P,DM2,A,DM3,DCR,DM4
      EQUIVALENCE (DATA,LDATA)
      S=FLOATF(XSIGNF(1,ILK))
      DO 2 I =1,6
      IF(I-XABSF(ILK))2,1,3
 1    GO TO( 21,22,23,26,26,26),I
 2    CONTINUE
 3    WRITE OUTPUT TAPE 6,4
 4    FORMAT(47H1      ERROR IN SURFACE TYPE, SUBROUTINE VECTOR   )
      CALL EXIT
C     RECTANGLE
 21   B(1) = A(1)
      B(2) = A(2)
      B(3) = A(3)
      C(1) = DB*DG*S
      C(2) = 0.
      C(3) = 0.
      GO TO 90
C     DISK
   22 X=COSF(A(3))
      Y = SINF(A(3))
      Z=A(2)*DG*DCR*S
      B(1)=A(1)
      B(2)=A(2)*X
```


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```
      B(3)=A(2)*Y
      C(1) = X*Z*DB*X + Y*Z*DB*Y
      C(2) = 0.
      C(3) = 0.
      GO TO 90
C     TRIANGLE
   23 X=SINF(A(3))/COSF(A(3))
      Y=A(2)*DG*DCR*S
      B(1)=A(1)
      B(2) = A(2)
      B(3)=A(2)*X
      C(1) = Y*DB + X*Y*DB*X
      C(2) =0.
      C(3) =0.
      GO TO 90
C     SPHERE
   26 W=SINF(A(2))
      X=COSF(A(2))
      Y=SINF(A(3))
      Z=COSF(A(3))
      V=A(1)*DB*DCR
      U=A(1)*DG*DCR*W*S
      B(1)=A(1)*X
      B(2)=A(1)*W*Z
      B(3)=A(1)*W*Y
      C(1) = U*Z*V*X*Z + U*Y*V*X*Y
      C(2) = U*Z*V*W
      C(3) = U*Y*V*W
 80   ARA(N,1) = P(J,3,3)*C(1) +P(J,3,2)*C(2) +P(J,3,1)*C(3)
      ARA(N,2) = P(J,2,3)*C(1) +P(J,2,2)*C(2) +P(J,2,1)*C(3)
      ARA(N,3) = P(J,1,3)*C(1) +P(J,1,2)*C(2) +P(J,1,1)*C(3)
      GO TO 100
 90   ARA(N,1) = P(J,3,3)*C(1)
      ARA(N,2) = P(J,2,3)*C(1)
      ARA(N,3) = P(J,1,3)*C(1)
 100  POS(N,1) = P(J,3,3)*B(1) +P(J,3,2)*B(2) +P(J,3,1)*B(3)+DATA(J,11)
      POS(N,2) = P(J,2,3)*B(1) +P(J,2,2)*B(2) +P(J,2,1)*B(3)+DATA(J,12)
      POS(N,3) = P(J,1,3)*B(1) +P(J,1,2)*B(2) +P(J,1,1)*B(3)+DATA(J,13)
      RETURN
      END


*     FORTRAN
      SUBROUTINE OMEGA
      DIMENSION DATA(22,16),LDATA(22,16),POS(1000,3),ARA(1000,3),FA(57,
     157),AREA(57),COST(37),DM1(268),DM2(3),NTN(57)
      DIMENSION SPRD(3)
      COMMON DATA,POS,ARA,FA,AREA,COST,DM1,SHD,NITE,IZ,IK,DM2,NV,NTN,
     1 RAD,PI
      EQUIVALENCE (DATA,LDATA)
      JU = NTN(NV)
      LKR = 1
      DO 2 I =1,37
 2    COST(I) = 0.
```


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      IF(IZ)6,3,6
3     IF(IK)4,5,4
4     IU = NTN(37)
      NVV = 37
      GO TO 8
5     IU = 1
      NVV =1
      GO TO 8
6     IU = JU
      NVV = NV
8     DO 12 I =1,NVV
      AREA(I) = 0.
      DO 12 J =1,NV
12    FA(I,J) = 0.
      DO 100 I =1,IU
      JL = I +1
      IF(I -1)16,17,16
16    IF(NTN(LKR) -I)18,19,19
17    AREA(1) = SQRTF((ARA(1,1)/1.0E+10)**2 + (ARA(1,2)/1.0E+10)**2
     1 + (ARA(1,3)/1.0E+10)**2 )*1.0E+10
      GO TO 21
18    LKR = LKR +1
19    AREA(LKR) = AREA(LKR) + SQRTF(ARA(I,1)**2 +ARA(I,2)**2 +
     1 ARA(I,3)**2 )
      IF(JL -IU)21,20,20
20    IF(IZ)100,21,100
21    LKE = LKR
      KK = 1
      KAT = I -NTN(37)
      DO 99 J = JL,JU
      IF(NTN(LKE) -J)23,26,26
23    LKE = LKE +1
26    DO 28 K =1,3
28    SPRD(K) = POS(J,K) -POS(I,K)
      TEST = ARA(I,1)*SPRD(1) +ARA(I,2)*SPRD(2) +ARA(I,3)*SPRD(3)
      IF(TEST)99,99,30
30    TESTJ = ARA(J,1)*SPRD(1) +ARA(J,2)*SPRD(2) +ARA(J,3)*SPRD(3)
      KIT = J -NTN(37)
      IF(I -1)32,32,35
32    IF(KIT)33,33,35
33    COST(LKE) = COST(LKE) -TESTJ/SQRTF (ARA(J,1)**2 +ARA(J,2)**2 +
     1 ARA(J,3)**2) / SQRTF(SPRD(1)**2 +SPRD(2)**2 +SPRD(3)**2)
35    IF(TESTJ)37,99,99
37    IF(KIT)95,95,38
38    IF(NITE -I)39,100,39
39    IF(SHD)95,95,44
44    CALL SHADE (I,J,KK,NAP,KAT)
      IF(NAP)95,95,99
95    DIST  = SPRD(1)**2 +SPRD(2)**2 +SPRD(3)**2
      FA(LKR,LKE) =FA(LKR,LKE) -(TEST/DIST)*(TESTJ/DIST)
99    CONTINUE
100   CONTINUE
      ABC = FLOATF(LDATA(2,2)*LDATA(2,3))
      DO 103 I =1,37
103   COST(I) = COST(I)/ABC
```

```
      DO 107 I =1,NVV
      FA(I,I) = FA(I,I)/PI*2.0
      JL = I +1
      DO 107 J = JL,NV
      FA(I,J) = FA(I,J)/PI
  107 FA(J,I) = FA(I,J)
      RETURN
      END


*     FORTRAN
      SUBROUTINE SHADE(I,J,KK,NAP,KAT)
      DIMENSION DATA(22,16),LDATA(22,16),POS(1000,3),ARA(1000,3),DM1(34
     109),P(22,3,3),DM2(3),DM3(8),NTN(57)
      COMMON DATA,POS,ARA,DM1,P,DM2,NS,DM3,NTN
      EQUIVALENCE (DATA,LDATA)
      LL = 37
      KT = 1
      K =2
    5 K =K +1
      IF(K -NS)10,10,6
    6 NAP =-1
      GO TO 201
   10 LL = LL +LDATA(K,4)*LDATA(K,5)
      L = NTN(LL)
      MA = XABSF(LDATA(K,1))
      IF(KT)12,22,12
   12 IF(KAT)15,15,18
   15 IF(KK)20,20,16
   16 KK =0
      GAM = SQRTF(POS(I,1)**2 +POS(I,2)**2 +POS(I,3)**2)
      GAMZ = POS(I,1)/GAM
      GAMY = POS(I,2)/GAM
      GAMX = POS(I,3)/GAM
      PII= POS(I,1) +POS(I,2) +POS(I,3)
      GO TO 20
   18 DNZ = POS(I,1) -POS(J,1)
      DNY = POS(I,2) -POS(J,2)
      DNX = POS(I,3) -POS(J,3)
      PI = POS(I,1) +POS(I,2) +POS(I,3)
   20 PJ = POS(J,1) +POS(J,2) +POS(J,3)
      KT =0
   22 IF(NTN(LL) -J)25,5,24
   24 IF(NTN(LL-1) - J)5,25,25
   25 BK =ARA(L,3)*(POS(L,3) -POS(J,3)) +ARA(L,2)*(POS(L,2) -POS(J,2))
     1 +ARA(L,1)*(POS(L,1) -POS(J,1))
      IF(KAT)33,33,27
   27 BA = ARA(L,3)*DNX +ARA(L,2)*DNY +ARA(L,1)*DNZ
      IF(ABSF(BA) -1.0E-6)5,5,30
   30 IF(NTN(LL) -I)32,5,31
   31 IF(NTN(LL -1) - I)5,32,32
   32 BK =BK/BA
      PZ = POS(J,1) +BK*DNZ
      PY = POS(J,2) +BK*DNY
```

```
      PX = POS(J,3) +BK*DNX
      A = PX +PY +PZ
      A = (A -PI)/(PJ -A)
      GO TO 35
 33   BA = ARA(L,3)*GAMX +ARA(L,2)*GAMY +ARA(L,1)*GAMZ
      IF(ABSF(BA) -1.0E-6)5,5,34
 34   BK = BK/BA
      PZ = POS(J,1) +BK*GAMZ
      PY = POS(J,2) +BK*GAMY
      PX = POS(J,3) +BK*GAMX
      A =-PII/(PJ -PX -PY -PZ)
 35   IF(A)5,5,37
 37   PYY = P(K,1,2)*(PX -DATA(K,13)) +P(K,2,2)*(PY -DATA  ,12))
     1 +P(K,3,2)*(PZ -DATA(K,11))
      PX = P(K,1,1)*(PX -DATA(K,13)) +P(K,2,1)*(PY -DATA(  12))
     1 +P(K,3,1)*(PZ -DATA(K,11))
      PY = PYY
      GO TO (40,50,60 ),MA
C     FLAT PLATE
 40   IF(PY - DATA(K,7))5,43,42
 42   IF(PY - DATA(K,9))43,43,5
 43   IF(PX - DATA(K,8))5,200,44
 44   IF(PX -DATA(K,10))200,200,5
C     DISK
 50   R = SQRTF(PX**2 +PY**2)
      IF(R -DATA(K,9))51,53,5
 51   IF(R -DATA(K,7))5,53,53
 53   IF(PX)55,54,54
 54   GR =ACOSF(PY/R)
      GO TO 57
 55   GR = 360.-ACOSF(PY/R)
 57   IF(GR-DATA(K,8))5,200,58
 58   IF(GR -DATA(K,10))200,200,5
C     TRIANGLE
 60   IF(PY -DATA(K,7))5,63,61
 61   IF(PY -DATA(K,9))63,63,5
 63   R = SQRTF(PX**2 + PY**2)
      IF(PX)65,64,64
 64   GR =ACOSF(PY/R)
      GO TO 67
 65   GR = 360. -ACOSF(PY/R)
 67   IF(GR -DATA(K,8))5,200,68
 68   IF(GR -DATA(K,10))200,200,5
 200  NAP =1
 201  RETURN
      END


      FORTRAN
      SUBROUTINE FLUX
      DIMENSION DATA(22,16),LDATA(22,16),DM1(6000),FA(57,5 ),AREA(57),
     1COST(37),AS(22),AA(22),E(22),DM2(201),DM3(3),DM4(61),  N(2),DM5(40)
     2 ,FXS(20,40),FXA(20,40),FXP(20,40),FLUXS(20,40),FLUXA 20,40),FLUXP
     3 (20,40),B(21,21),DM6(135),RADK(21,21)
```

```
      DIMENSION WP(37),Q(3,20),GS(21,21),GP(21),GA(21),TEMP(21),TAS(22)
     1 ,TAA(22),TE(22)
      COMMON DATA,DM1,FA,AREA,COST,AS,AA,E,DM2,NS,SHD,NITE,IZ,IK,DM3,
     1 NV,DM4,IN,DM5,FXS,FXA,FXP,FLUXS,FLUXA,FLUXP,B,DM6,NTABLE,SBC,TSUN
     2 ,TSS,TDS,RADK
      EQUIVALENCE (DATA,LDATA)
      LI = LI +1
      IF(IZ)2,6,2
    2 LI = 1
      WSUN = SBC*TSUN**4
      DT1 = TSS -TDS
      DT2 = (1.0 -AS(2))*WSUN
      NVS =NV -37
      NS1 =NVS +1
      NS2 = NVS +2
      IF(NS +35 -NV)3,6,6
    3 DO 4 I = 3,NS
      TAS(I) = AS(I)
      TAA(I) = AA(I)
    4 TE(I) = E(I)
      LA = 0
      DO 5 I = 3,NS
      LB = LA +1
      LA = LA +LDATA(I,4)*LDATA(I,5)
      DO 5 J = LB,LA
      J1 = J + 2
      AS(J1) = TAS(I)
      AA(J1) = TAA(I)
    5 E(J1) = TE(I)
    6 DO 10 I =2,37
      WP(I) =TDS
      IF(COST(I))10,10,7
    7 WP(I) = WP(I) +DT1*COST(I)
   10 WP(I) = SBC*WP(I)**4
      WPE = 0.
      APLAN =0.
      DO 12 I =2,37
      WPE = WPE +AREA(I)*WP(I)
   12 APLAN = APLAN +AREA(I)
      WPE = WPE/APLAN
      DO 20 I =38,NV
      I1 =I -37
      Q(1,I1) = FA(1,I)*WSUN
      Q(2,I1) = 0.
      Q(3,I1) = 0.
      DO 19 J =2,37
      Q(2,I1) = Q(2,I1) +FA(J,I)*(FA(1,J)/AREA(J))
   19 Q(3,I1) = Q(3,I1) +FA(J,I)*WP(J)
   20 Q(2,I1) = Q(2,I1)*DT2
      IF(IK)25,24,25
   24 IF(IZ)25,60,25
C     ASSIGN PLANETSHINE MATRIX
   25 B(1,1) =1.
      GS(1,1) = 0.
      DO 30 I =2,NS1
```


230

```
      TEMP(I) = Q(3,I-1)/WPE
      B(I,1) = 0.
   30 GS(I,1) = TEMP(I)
      DO 35 J =2,NS1
      J1 =J +36
      J2 = J + 1
      DT =(E(J2) -1.0)/E(J2)/AREA(J1)
      B(1,J) = DT*TEMP(J)
      GS(1,J) = E(J2)*TEMP(J)
      DO 34 I =2,NS1
      I1 = I +36
      B(I,J) = DT*FA(J1,I1)
   34 GS(I,J) = E(J2)*FA(J1,I1)
   35 B(J,J) = B(J,J) + 1.0/E(J2)
      CALL INVERT(NS1)
      DO 45 J =1,NS1
      DO 44 I =1,NS1
      TEMP(I) = 0.
      DO 44 K =1,NS1
   44 TEMP(I) = TEMP(I) +B(I,K)*GS(K,J)
      DO 45 I =1,NS1
   45 GS(I,J) = TEMP(I)
      DO 46 I =2,NS1
   46 GP(I) = GS(1,I)
      IF(IZ)50,60,50
   50 DO 55 I =1,NVS
      I1 =I +1
      I2 =I +2
      I3 =I +37
      TEMP(I) =0.
      DO 54 J =1,NVS
      J1 =J +1
      RADK(I,J) = GS(I1,J1)*SBC
   54 TEMP(I) = TEMP(I) +GS(I1,J1)
   55 RADK(I,21) =(E(I2)*AREA(I3) -TEMP(I))*SBC
C     ASSIGN ALBEDO MATRIX
   60 B(1,1) =1.
      GS(1,1) = 0.
      DO 62 I = 2,NS1
      TEMP(I) =Q(2,I-1)/WSUN
      B(I,1) =0.
   62 GS(I,1) = TEMP(I)
      DO 68 J =2,NS1
      J1 = J+36
      J2 = J + 1
      DT = (AA(J2) -1.0)/AA(J2)/AREA(J1)
      B(1,J) = DT*TEMP(J)
      GS(1,J) = AA(J2)*TEMP(J)
      DO 67 I =2,NS1
      I1 = I+ 36
      B(I,J) = DT*FA(J1,I1)
   67 GS(I,J) = AA(J2)*FA(J1,I1)
   68 B(J,J) =B(J,J) +1.0/AA(J2)
      CALL INVERT(NS1)
      DO 75 J=1,NS1
```


231

```
      DO 74 I=1,NS1
      TEMP(I) = 0.
      DO 74 K =1,NS1
74    TEMP(I) =TEMP(I) +B(I,K)*GS(K,J)
      DO 75 I =1,NS1
75    GS(I,J) = TEMP(I)
      DO 77 I =2,NS1
77    GA(I) =GS(1,I)
      IF(NITE)84,84,80
80    DO 81 I = 2,NS1
81    GS(1,I) = 0.
      GO TO 100
C     ASSIGN SOLAR MATRIX
84    B(1,1) = 1.
      GS(1,1) = 0.
      DO 87 J=2,NS1
      J1 = J +36
      J2 = J + 1
      DT = (AS(J2) -1.0)/AS(J2)/AREA(J1)
      B(J,1) = 0.
      GS(J,1) = FA(1,J1)
      B(1,J) = DT*FA(J1,1)
      GS(1,J) = AS(J2)*FA(J1,1)
      DO 86 I =2,NS1
      I1 = I +36
      B(I,J) =DT*FA(J1,I1)
86    GS(I,J) = AS(J2)*FA(J1,I1)
87    B(J,J) = B(J,J) + 1.0/AS(J2)
      CALL INVERT(NS1)
      DO 95 J =1,NS1
      DO 94 I =1,NS1
      TEMP(I) = 0.
      DO 94 K =1,NS1
94    TEMP(I) = TEMP(I) + B(I,K)*GS(K,J)
      DO 95 I = 1,NS1
95    GS(I,J) = TEMP(I)
100   GO TO (105,110),NTABLE
105   DO 107 I =1,NVS
      I1 = I +37
      FXS(I,LI) =(Q(1,I) + Q(2,I))/AREA(I1)
      FXP(I,LI) = Q(3,I)/AREA(I1)
      I2 = I +1
      FLUXS(I,LI) =(GS(1,I2) +GA(I2))*WSUN
107   FLUXP(I,LI) = GP(I2)*WPE
      GO TO 115
110   DO 112 I =1,NVS
      I1 =I +37
      I2 = I +1
      FXS(I,LI) =Q(1,I)/AREA(I1)
      FXA(I,LI) =Q(2,I)/AREA(I1)
      FXP(I,LI) =Q(3,I)/AREA(I1)
      FLUXS(I,LI) = GS(1,I2)*WSUN
      FLUXA(I,LI) = GA(I2)*WSUN
112   FLUXP(I,LI) = GP(I2)*WPE
115   IF(LI -IN(2))140,120,140
```

```
120   LK = LI +1
      GO TO (125,130),NTABLE
125   DO 127 I =1,NVS
      I1 = I +37
      FXS(I,LK) = FXS(I,LI)
      FXS(I,LI) = Q(2,I)/AREA(I1)
      FXP(I,LK) = FXP(I,LI)
      FLUXS(I,LK) = FLUXS(I,LI)
      FLUXS(I,LI) = GA(I+1)*WSUN
127   FLUXP(I,LK) = FLUXP(I,LI)
      GO TO 160
130   DO 132 I =1,NVS
      I1 = I +37
      FXS(I,LK) = FXS(I,LI)
      FXS(I,LI) = 0.
      FXA(I,LK) = FXA(I,LI)
      FXP(I,LK) = FXP(I,LI)
      FLUXS(I,LK) =FLUXS(I,LI)
      FLUXS(I,LI) = 0.
      FLUXA(I,LK) = FLUXA(I,LI)
132   FLUXP(I,LK) = FLUXP(I,LI)
      GO TO 160
140   IF(LI +1 -IN(1))170,142,170
142   LK = LI +1
      GO TO (145,150),NTABLE
145   DO 147 I =1,NVS
      I1 =I +37
      FXS(I,LK) = Q(2,I)/AREA(I1)
      FXP(I,LK) = FXP(I,LI)
      FLUXS(I,LK) = GA(I+1)*WSUN
147   FLUXP(I,LK) = FLUXP(I,LI)
      GO TO 160
150   DO 152 I =1,NVS
      FXS(I,LK) =0.
      FXA(I,LK) =FXA(I,LI)
      FXP(I,LK) =FXP(I,LI)
      FLUXS(I,LK) = 0.
      FLUXA(I,LK) = FLUXA(I,LI)
152   FLUXP(I,LK) = FLUXP(I,LI)
160   LI = LI + 1
170   RETURN
      END
```

```
      FORTRAN
      SUBROUTINE INVERT (NN)
      DIMENSION DM1(14874),A(21,21),IN(21),TEMP(21)
      COMMON DM1,A
      NS=NN
 59   IN=0
      IMAXO=NS-1
      TEMP=A
      DO 70 I=2,NS
      IF(ABSF(TEMP)-ABSF(A(I,1))) 71,70,70
```

```
 71   IN=I
      TEMP=A(I,1)
 70   CONTINUE
      IF(IN) 73,72,73
 73   IS=IN
      DO 74 J=1,NS
      TEMP=A(1,J)
      A(1,J)=A(IS,J)
 74   A(IS,J)=TEMP
 72   IF(A) 98,99,98
 98   DO 75 I=2,NS
 75   A(I,1)=A(I,1)/A
      DO 100 I=2,NS
      IPO=I+1
      IMO=I-1
      DO 80 L=1,IMO
 80   A(I,I)=A(I,I)-A(L,I)*A(I,L)
      TEMP=A(I,I)
      IF(I-NS) 55,83,55
 55   IN(I)=0
      DO 81 IS=IPO,NS
      DO 85 L=1,IMO
 85   A(IS,I)=A(IS,I)-A(L,I)*A(IS,L)
      IF(ABSF(TEMP)-ABSF(A(IS,I))) 82,81,81
 82   TEMP=A(IS,I)
      IN(I)=IS
 81   CONTINUE
      ISS=IN(I)
      IF(ISS) 84,83,84
 84   DO 886 J=1,NS
      TEMP=A(I,J)
      A(I,J)=A(ISS,J)
886   A(ISS,J)=TEMP
 83   IF(A(I,I)) 97,99,97
 97   IF(I-NS) 54,100,54
 54   DO 86 IS=IPO,NS
 86   A(IS,I)=A(IS,I)/A(I,I)
      DO 89 JS=IPO,NS
      DO 89 L=1,IMO
 89   A(I,JS)=A(I,JS)-A(L,JS)*A(I,L)
100   CONTINUE
      DO 600 JP=1,NS
      J=NS+1-JP
      A(J,J)=1./A(J,J)
      IF(J-1) 603,700,603
603   DO 600 IP=2,J
      I=J+1-IP
      IPO=I+1
      TEMP=0.
      DO 602 L=IPO,J
602   TEMP=TEMP-A(I,L)*A(L,J)
600   A(I,J)=TEMP/A(I,I)
700   DO 151 J=1,IMAXO
      JPO=J+1
      DO 151 I=JPO,NS
```

```
      TEMP=0.
      IMO=I-1
      DO 154 L=J,IMO
      IF(L-J) 152,153,152
  152 TEMP=TEMP-A(I,L)*A(L,J)
      GO TO 154
  153 TEMP=TEMP-A(I,L)
  154 CONTINUE
  151 A(I,J)=TEMP
      DO 901 I=1,NS
      DO 900 J=1,NS
      TEMP(J)=0.
      DO 899 N=I,NS
      IF(N-J) 899,897,898
  898 TEMP(J)=TEMP(J)+A(I,N)*A(N,J)
      GO TO 899
  897 TEMP(J)=TEMP(J)+A(I,N)
  899 CONTINUE
  900 CONTINUE
      DO 901 J=1,NS
  901 A(I,J)=TEMP(J)
      DO 500 I=1,NS
      M=NS+1-I
      IF(IN(M)) 502,500,502
  502 ISS=IN(M)
      DO 503 L=1,NS
      TEMP=A(L,ISS)
      A(L,ISS)=A(L,M)
  503 A(L,M)=TEMP
  500 CONTINUE
    1 RETURN
   99 WRITE OUTPUT TAPE 6,200
  200 FORMAT(50H1RADK MATRIX IS SINGULAR. PROGRAM CANNOT CONTINUE.)
      CALL EXIT
      END


*     FORTRAN
      SUBROUTINE OUTPUT(NVAR,NCARDS,NFORMT,MAN,THETIN,THETFI)
      DIMENSION DM1(9601),AREA(57),DM2(312),DM3(58),DM4(2),IN(2),TIME(4
     10),FXS(20,40),FXA(20,40),FXP(20,40),FLUXS(20,40),FLUXA(20,40),
     2 FLUXP(20,40),DM5(441),WRIT(22,6),DM6(2),RADK(21,21)
      COMMON DM1,AREA,DM2,NV,DM3,PI,DM4,IN,TIME,FXS,FXA,FXP,FLUXS,FLUXA
     1,FLUXP,DM5,WRIT,ECC,PERIOD,NPO,NTABLE,SBC,TSUN,DM6,RADK,THE,BETA,
     2 KAD,DSUN
1     FORMAT(1H1)
2     FORMAT(54H0PERCENT TIME IN SUN NOT CALCULATED FOR PARTIAL ORBIT )
3     FORMAT(/67H          RADIATION CONSTANTS FOR VEHICLE NODES.  SPACE
     1 = NUMBER 21    )
4     FORMAT( 34H1          PERCENT TIME IN THE SUN =F6.1,19X16HALPHA(S)
     1ANGLE =F7.1 //9X20HORBIT ECCENTRICITY =F7.4,23X12HBETA ANGLE =F7.1
     2// 9X16HSOLAR CONSTANT =E12.5 // 9X14HORBIT PERIOD =E12.5 )
5     FORMAT(9X2HK(I2,1H,I2,4H) = E12.5)
6     FORMAT(20H1  ERROR IN BLOCK 5 )
```

```
8       FORMAT(I5,41X31HSOLAR + ALBEDO, TOTAL ABSORBED  )
9       FORMAT(I5,10XE15.5,16X31HSOLAR + ALBEDO, TOTAL ABSORBED )
10      FORMAT(I5,41X31HSOLAR + ALBEDO, DIRECT INCIDENT )
11      FORMAT(I5,10XE15.5,16X31HSOLAR + ALBEDO, DIRECT INCIDENT )
13      FORMAT(15X2E15.5,1X5A6,A4)
14      FORMAT(15X2E15.5 )
15      FORMAT(/I5,41X28HPLANETSHINE, TOTAL ABSORBED  )
16      FORMAT(/I5,10XE15.5,16X28HPLANETSHINE, TOTAL ABSORBED  )
17      FORMAT(/I5,41X28HPLANETSHINE, DIRECT INCIDENT )
18      FORMAT(/I5,10XE15.5,16X28HPLANETSHINE, DIRECT INCIDENT )
19      FORMAT(/I5,41X22HSOLAR, TOTAL ABSORBED  )
20      FORMAT(/I5,10XE15.5,16X22HSOLAR, TOTAL ABSORBED )
21      FORMAT(/I5,41X22HSOLAR, DIRECT INCIDENT )
22      FORMAT(/I5,10XE15.5,16X22HSOLAR, DIRECT INCIDENT )
24      FORMAT(/I5,41X23HALBEDO, TOTAL ABSORBED  )
25      FORMAT(/I5,10XE15.5,16X23HALBEDO, TOTAL ABSORBED )
26      FORMAT(/I5,41X23HALBEDO, DIRECT INCIDENT )
27      FORMAT(/I5,10XE15.5,16X23HALBEDO, DIRECT INCIDENT )
        NVS = NV -37
        NS1 = NVS+ 1
        IF(NVAR)70,70,51
51      SOLAR = SBC*AREA(1)/PI*TSUN**4/DSUN**2
        IF(KAD)54,54,53
53      WRITE OUTPUT TAPE 6,2
        PSS =0.
        GO TO 66
54      IN2 = IN(2)
        IN1 = IN(1)
        IF(MAN)56,58,58
56      PSS = TIME(IN1) - TIME(IN2)
        GO TO 60
58      PSS = TIME(IN1) + PERIOD - TIME(IN2)
60      IF(PSS)64,64,62
62      PSS = PSS/PERIOD*100.
        GO TO 66
64      PSS = 100.
66      WRITE OUTPUT TAPE 6,4,PSS,THE,ECC,BETA,SOLAR,PERIOD
        WRITE OUTPUT TAPE 6,3
        J1 =1
        DO 68 I =1,NVS
        J1 =J1 +1
68      WRITE OUTPUT TAPE 6,5,(I,J,RADK(I,J),J =J1,NVS)
        J = 21
        WRITE OUTPUT TAPE 6,5,(I,J,RADK(I,J), I =1,NVS)
70      IF(NFORMT -2)75,75,76
75      GO TO (100,100),NFORMT
76      WRITE OUTPUT TAPE 6,6
100     WRITE OUTPUT TAPE 6,1
        GO TO (101,201),NTABLE
101     DO 130 I =1,NVS
        N =2*I -1
        IF(KAD)104,104,103
103     WRITE OUTPUT TAPE 6,8,N
        GO TO 105
104     WRITE OUTPUT TAPE 6,9,N,PERIOD
```


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```
105   WRITE OUTPUT TAPE 6,13,TIME(1),FLUXS(I,1),(WRIT(I,J),J=1,6)
      WRITE OUTPUT TAPE 6,14,(TIME(J),FLUXS(I,J),J =2,NPO )
      IF(KAD)108,108,109
108   WRITE OUTPUT TAPE 6,14,PERIOD,FLUXS(I,1)
109   IF(NPO - 24)113,113,111
111   WRITE OUTPUT TAPE 6,1
113   K = I+I
      IF(KAD)119,119,117
117   WRITE OUTPUT TAPE 6,15,K
      GO TO 121
119   WRITE OUTPUT TAPE 6,16,K,PERIOD
121   WRITE OUTPUT TAPE 6,13,TIME(1),FLUXP(I,1),(WRIT(I,J),J =1,6)
      WRITE OUTPUT TAPE 6,14,(TIME(J),FLUXP(I,J),J=2,NPO)
      IF(KAD)125,125,130
125   WRITE OUTPUT TAPE 6,14,PERIOD,FLUXP(I,1)
130   WRITE OUTPUT TAPE 6,1
      DO 155 I=1,NVS
      N =2*I -1
      IF(KAD)133,133,132
132   WRITE OUTPUT TAPE 6,10,N
      GO TO 134
133   WRITE OUTPUT TAPE 6,11,N,PERIOD
134   WRITE OUTPUT TAPE 6,13,TIME(1),FXS(I,1),(WRIT(I,J),J=1,6)
      WRITE OUTPUT TAPE 6,14,(TIME(J),FXS(I,J), J=2,NPO)
      IF(KAD)137,137,139
137   WRITE OUTPUT TAPE 6,14,PERIOD,FXS(I,1)
139   IF(NPO -24)142,142,140
140   WRITE OUTPUT TAPE 6,1
142   K = I +I
      IF(KAD)146,146,145
145   WRITE OUTPUT TAPE 6,17,K
      GO TO 147
146   WRITE OUTPUT TAPE 6,18,K,PERIOD
147   WRITE OUTPUT TAPE 6,13,TIME(1),FXP(I,1),(WRIT(I,J),J=1,6)
      WRITE OUTPUT TAPE 6,14,(TIME(J),FXP(I,J),J =2,NPO)
      IF(KAD)150,150,155
150   WRITE OUTPUT TAPE 6,14,PERIOD,FXP(I,1)
155   WRITE OUTPUT TAPE 6,1
       IF(NCARDS -1)500,159,156
156    IF(NCARDS-2)180,180,157
157   NP =1
      GO TO 160
159   NP = -1
160   DO 176 I = 1,NVS
      N = 2*I -1
      IF(KAD)163,163,162
162   PUNCH 8,N
      GO TO 164
163   PUNCH 9,N,PERIOD
164   PUNCH 13,TIME(1),FLUXS(I,1),(WRIT(I,J),J=1,6)
      PUNCH 14,(TIME(J),FLUXS(I,J),J =2,NPO )
      IF(KAD)166,166,167
166   PUNCH 14,PERIOD,FLUXS(I,1)
167   K = 2*I
      IF(KAD)170,170,169
```

```
169    PUNCH 15,K
       GO TO 171
170    PUNCH 16,K,PERIOD
171    PUNCH 13,TIME(1),FLUXP(I,1),(WRIT(I,J),J=1,6)
       PUNCH 14,(TIME(J),FLUXP(I,J),J =2,NPO)
       IF(KAD)173,173,176
173    PUNCH 14, PERIOD,FLUXP(I,1)
176    CONTINUE
       IF(NP)500,500,180
180    DO 198 I =1,NVS
       N = 2*I -1
       IF(KAD)183,183,182
182    PUNCH 10,N
       GO TO 184
183    PUNCH 11,N,PERIOD
184    PUNCH 13,TIME(1),FXS(I,1),(WRIT(I,J),J=1,6)
       PUNCH 14,(TIME(J),FXS(I,J),J=2,NPO)
       IF(KAD)186,186,188
186    PUNCH 14,PERIOD,FXS(I,1)
188    K = I+I
       IF(KAD)190,190,189
189    PUNCH 17,K
       GO TO 191
190    PUNCH 18,K,PERIOD
191    PUNCH 13,TIME(1),FXP(I,1),(WRIT(I,J), J =1,6)
       PUNCH 14, (TIME(J),FXP(I,J), J =2,NPO)
       IF(KAD)193,193,198
193    PUNCH 14,PERIOD,FXP(I,1)
198    CONTINUE
       GO TO 500
201    M = 0
       DO 226 I =1,NVS
       N =3*I -2
       IF(KAD)203,203,202
202    WRITE OUTPUT TAPE 6,19,N
       GO TO 204
203    WRITE OUTPUT TAPE 6,20,N,PERIOD
204    WRITE OUTPUT TAPE 6,13,TIME(1),FLUXS(I,1),(WRIT(I,J),J =1,6)
       WRITE OUTPUT TAPE 6,14,(TIME(J),FLUXS(I,J),J = 2,NPO )
       IF(KAD)206,206,207
206    WRITE OUTPUT TAPE 6,14,PERIOD,FLUXS(I,1)
207    K = 3*I -1
       M = M + NPO + 7
       IF(M -60)210,209,209
209    WRITE OUTPUT TAPE 6,1
       M = 0
210    IF(KAD)213,213,212
212    WRITE OUTPUT TAPE 6,24,K
       GO TO 214
213    WRITE OUTPUT TAPE 6,25,K,PERIOD
214    WRITE OUTPUT TAPE 6,13,TIME(1),FLUXA(I,1),(WRIT(I,J),J =1,6)
       WRITE OUTPUT TAPE 6,14,(TIME(J),FLUXA(I,J),J =2,NPO )
       IF(KAD)216,216,217
216    WRITE OUTPUT TAPE 6,14,PERIOD,FLUXA(I,1)
217    L = 3*I
```

```
      M = M +NPO +7
      IF(M -60)219,218,218
218   WRITE OUTPUT TAPE 6,1
      M = 0
219   IF(KAD)221,221,220
220   WRITE OUTPUT TAPE 6,15,L
      GO TO 222
221   WRITE OUTPUT TAPE 6,16,L,PERIOD
222   WRITE OUTPUT TAPE 6,13,TIME(1),FLUXP(I,1),(WRIT(I,J),J=1,6)
      WRITE OUTPUT TAPE 6,14,(TIME(J),FLUXP(I,J),J =2,NPO )
      IF(KAD)223,223,224
223   WRITE OUTPUT TAPE 6,14,PERIOD,FLUXP(I,1)
224   M = M +NPO +7
      IF(M -60)226,226,225
225   WRITE OUTPUT TAPE 6,1
      M =0
226   CONTINUE
      WRITE OUTPUT TAPE 6,1
      M = 0
      DO 255 I =1,NVS
      N = 3*I -2
      IF(KAD)229,229,228
228   WRITE OUTPUT TAPE 6,21,N
      GO TO 230
229   WRITE OUTPUT TAPE 6,22,N,PERIOD
230   WRITE OUTPUT TAPE 6,13,TIME(1),FXS(I,1),(WRIT(I,J), J =1,6)
      WRITE OUTPUT TAPE 6,14, (TIME(J),FXS(I,J), J =2,NPO)
      IF(KAD)232,232,233
232   WRITE OUTPUT TAPE 6,14,PERIOD,FXS(I,1)
233   K = 3*I -1
     M = M +NPO +7
      IF(M -60 )236,235,235
235   WRITE OUTPUT TAPE 6,1
      M = 0
236   IF(KAD)238,238,237
237   WRITE OUTPUT TAPE 6,26,K
      GO TO 239
238   WRITE OUTPUT TAPE 6,27,K,PERIOD
239   WRITE OUTPUT TAPE 6,13,TIME(1),FXA(I,1),(WRIT(I,J), J =1,6)
      WRITE OUTPUT TAPE 6,14, (TIME(J),FXA(I,J), J =2,NPO)
      IF(KAD)241,241,242
241   WRITE OUTPUT TAPE 6,14,PERIOD,FXA(I,1)
242   L = 3*I
      M = M +NPO +7
      IF(M -60)244,243,243
243   WRITE OUTPUT TAPE 6,1
      M = 0
244   IF(KAD)247,247,246
246   WRITE OUTPUT TAPE 6,17,L
      GO TO 248
247   WRITE OUTPUT TAPE 6,18,L,PERIOD
248   WRITE OUTPUT TAPE 6,13,TIME(1),FXP(I,1), (WRIT(I,J), J =1,6)
      WRITE OUTPUT TAPE 6,14,(TIME(J),FXP(I,J), J =2,NPO)
      IF(KAD)250,250,251
250   WRITE OUTPUT TAPE 6,14,PERIOD,FXP(I,1)
```

```
251   M = M +NPO +7
      IF(M -60)255,255,253
253   WRITE OUTPUT TAPE 6,1
      M = 0
255   CONTINUE
      IF(NCARDS -1)500,259,257
257   IF(NCARDS -2)283,283,258
258   NP = 1
      GO TO 260
259   NP = -1
260   DO 280 I =1,NVS
      N = 3*I -2
      IF(KAD)263,263,262
262   PUNCH 19,N
      GO TO 264
263   PUNCH 20,N,PERIOD
264   PUNCH 13,TIME(1),FLUXS(I,1),(WRIT(I,J),J =1,6)
      PUNCH 14,(TIME(J),FLUXS(I,J),J =2,NPO )
      IF(KAD)266,266,267
266   PUNCH 14, PERIOD,FLUXS(I,1)
267   K =3*I -1
      IF(KAD)269,269,268
268   PUNCH 24,K
      GO TO 270
269   PUNCH 25,K,PERIOD
270   PUNCH 13,TIME(1),FLUXA(I,1),(WRIT(I,J),J =1,6)
      PUNCH 14,(TIME(J),FLUXA(I,J), J=2,NPO )
      IF(KAD)272,272,273
272   PUNCH 14,PERIOD,FLUXA(I,1)
273   L = 3*I
      IF(KAD)276,276,275
275   PUNCH 15,L
      GO TO 277
276   PUNCH 16,L,PERIOD
277   PUNCH 13,TIME(1),FLUXP(I,1),(WRIT(I,J),J =1,6)
      PUNCH 14,(TIME(J),FLUXP(I,J), J= 2,NPO )
      IF(KAD)279,279,280
279   PUNCH 14,PERIOD,FLUXP(I,1)
280   CONTINUE
      IF(NP)500,500,283
283   DO 299 I =1,NVS
      N = 3*I -2
      IF(KAD)285,285,284
284   PUNCH 21, N
      GO TO 286
285   PUNCH 22,N,PERIOD
286   PUNCH 13,TIME(1),FXS(I,1),(WRIT(I,J), J =1,6)
      PUNCH 14, (TIME(J),FXS(I,J), J =2,NPO)
      IF(KAD)287,287,288
287   PUNCH 14, PERIOD,FXS(I,1)
288   K = 3*I -1
      IF(KAD)291,291,290
290   PUNCH 26,K
      GO TO 292
291   PUNCH 27,K,PERIOD
```

```
  292   PUNCH 13, TIME(1),FXA(I,1),(WRIT(I,J), J =1,6)
        PUNCH 14, (TIME(J),FXA(I,J), J =2,NPO)
        IF(KAD)293,293,294
  293   PUNCH 14,PERIOD,FXA(I,1)
  294   L = 3*I
        IF(KAD)296,296,295
  295   PUNCH 17, L
        GO TO 297
  296   PUNCH 18,L,PERIOD
  297   PUNCH 13, TIME(1),FXP(I,1), (WRIT(I,J), J =1,6)
        PUNCH 14, (TIME(J),FXP(I,J), J =2,NPO)
        IF(KAD)298,298,299
  298   PUNCH 14,PERIOD,FXP(I,1)
  299   CONTINUE
        GO TO 500
  500   RETURN
        END


*       FAP
        COUNT   500
        LBL     TAN,2
        ENTRY   TAN
TAN     UFA     =0233000000000
        STQ     11
        STQ     11+1
        SXA     BACK,2
        SXA     BACK+1,4
        ANA     =0777777777
        XCA
        CLM
        DVP     =45
        PAX     0,2
        XCA
        ANA     =3
        PAX     0,4
        CLA     11
        SSP
        CAS     =.5
        TRA     INC2
        NOP
OKINT   XCA
        TRA     01,4
        TRA     04
        TRA     03
        TRA     02
01      FMP     INT,2
        FAD     TANT,2
        TRA     BACK
02      PXD     0,2
        PDC     0,2
        TXI     *+1,2,45
        FMP     INT,2
        FSB     TANT,2
```

```
          CHS
          STO       1)
          CLA       =1.
          FDP       1)
          XCA
          TRA       BACK
03        FMP       INT,2
          FAD       TANT,2
          CHS
          STO       1)
          CLA       =1.
          FDP       1)
          XCA
          TRA       BACK
04        PXD       0,2
          PDC       0,2
          TXI       *+1,2,45
          FMP       INT,2
          FSB       TANT,2
BACK      AXT       **,2
          AXT       **,4
          LDQ       1)+1
          TQP       *+2
          CHS
          TRA       1,4
INC2      FSB       =1.
          TXI       OKINT,2,1
1)        OCT       ,
          DEC  +.10000000E+01
          DEC  +.96568877E+00
          DEC  +.93251507E+00
          DEC  +.90040405E+00
          DEC  +.86928673E+00
          DEC  +.83909962E+00
          DEC  +.80978402E+00
          DEC  +.78128562E+00
          DEC  +.75355406E+00
          DEC  +.72654252E+00
          DEC  +.70020753E+00
          DEC  +.67450851E+00
          DEC  +.64940758E+00
          DEC  +.62486934E+00
          DEC  +.60086062E+00
          DEC  +.57735028E+00
          DEC  +.55430905E+00
          DEC  +.53170943E+00
          DEC  +.50952544E+00
          DEC  +.48773258E+00
          DEC  +.46630764E+00
          DEC  +.44522868E+00
          DEC  +.42447482E+00
          DEC  +.40402622E+00
          DEC  +.38386403E+00
          DEC  +.36397023E+00
          DEC  +.34432760E+00
```

```
          DEC +.32491968E+00
          DEC +.30573067E+00
          DEC +.28674538E+00
          DEC +.26794919E+00
          DEC +.24932800E+00
          DEC +.23086819E+00
          DEC +.21255655E+00
          DEC +.19438030E+00
          DEC +.17632697E+00
          DEC +.15838444E+00
          DEC +.14054083E+00
          DEC +.12278456E+00
          DEC +.10510423E+00
          DEC +.87488662E-01
          DEC +.69926811E-01
          DEC +.52407778E-01
          DEC +.34920769E-01
          DEC +.17455065E-01
TANT      DEC +.
          DEC +.34906587E-01
          DEC +.33729447E-01
          DEC +.32630404E-01
          DEC +.31603158E-01
          DEC +.30642039E-01
          DEC +.29741951E-01
          DEC +.28898293E-01
          DEC +.28106909E-01
          DEC +.27364037E-01
          DEC +.26666259E-01
          DEC +.26010479E-01
          DEC +.25393874E-01
          DEC +.24813874E-01
          DEC +.24268136E-01
          DEC +.23754516E-01
          DEC +.23271058E-01
          DEC +.22815966E-01
          DEC +.22387600E-01
          DEC +.21984450E-01
          DEC +.21605136E-01
          DEC +.21248386E-01
          DEC +.20913034E-01
          DEC +.20598008E-01
          DEC +.20302319E-01
          DEC +.20025064E-01
          DEC +.19765406E-01
          DEC +.19522581E-01
          DEC +.19295886E-01
          DEC +.19084674E-01
          DEC +.18888354E-01
          DEC +.18706382E-01
          DEC +.18538267E-01
          DEC +.18383555E-01
          DEC +.18241838E-01
          DEC +.18112742E-01
          DEC +.17995937E-01
```

```
         DEC  +.17891120E-01
         DEC  +.17798025E-01
         DEC  +.17716420E-01
         DEC  +.17646098E-01
         DEC  +.17586885E-01
         DEC  +.17538635E-01
         DEC  +.17501229E-01
         DEC  +.17474576E-01
         DEC  +.17458610E-01
INT      DEC  +.17453292E-01
         END

*        FAP
         COUNT    200
         LBL      ATAN,2
         ENTRY    ATAN
ATAN     LAS      =1.
         TRA      TNBG
         TRA      EVEN
         SXA      BACK,4
         UFA      =0225000000000
         PAX      0,4
         STQ      1)
         XCA
         SSP
         CAS      =0172400000000
         TRA      INT4
         NOP
INTOK    XCA
         FMP      INT,4
         FAD      ATANT,4
         LDQ      1)
         TQP      *+2
         SSM
BACK     AXT      **,4
         TRA      1,4
INT4     FSB      =0173400000000
         TXI      INTOK,4,1
EVEN     CLM
         ORA      =45.
         TRA      1,4
TNBG     STO      1)
         CLA      =1.
         FDP      1)
         XCA
         SXA      *+2,4
         TSX      ATAN+3,4
         AXT      **,4
         TMI      *+4
         FSB      =90.
         CHS
         TRA      1,4
         FAD      =90.
```

```
        CHS
        TRA     1,4
11)     OCT
        DEC +.45000000E+02
        DEC +.44548713E+02
        DEC +.44090606E+02
        DEC +.43624860E+02
        DEC +.43151736E+02
        DEC +.42672007E+02
        DEC +.42184435E+02
        DEC +.41689010E+02
        DEC +.41185703E+02
        DEC +.40674473E+02
        DEC +.40155462E+02
        DEC +.39628682E+02
        DEC +.39093665E+02
        DEC +.38550342E+02
        DEC +.37998644E+02
        DEC +.37438495E+02
        DEC +.36869812E+02
        DEC +.36292516E+02
        DEC +.35706523E+02
        DEC +.35111743E+02
        DEC +.34508100E+02
        DEC +.33895917E+02
        DEC +.33274803E+02
        DEC +.32644636E+02
        DEC +.32005342E+02
        DEC +.31356855E+02
        DEC +.30699552E+02
        DEC +.30033274E+02
        DEC +.29357674E+02
        DEC +.28672934E+02
        DEC +.27979470E+02
        DEC +.27276630E+02
        DEC +.26564987E+02
        DEC +.25844343E+02
        DEC +.25114728E+02
        DEC +.24376440E+02
        DEC +.23629292E+02
        DEC +.22873612E+02
        DEC +.22109424E+02
        DEC +.21336711E+02
        DEC +.20556042E+02
        DEC +.19767109E+02
        DEC +.18970302E+02
        DEC +.18165951E+02
        DEC +.17354004E+02
        DEC +.16534735E+02
        DEC +.15708573E+02
        DEC +.14875672E+02
        DEC +.14036241E+02
        DEC +.13190590E+02
        DEC +.12339037E+02
        DEC +.11481907E+02
```

```
         DEC +.10619597E+02
         DEC +.97523929E+01
         DEC +.88806425E+01
         DEC +.80047207E+01
         DEC +.71250129E+01
         DEC +.62419129E+01
         DEC +.53558246E+01
         DEC +.44671587E+01
         DEC +.35763343E+01
         DEC +.26837752E+01
         DEC +.17899105E+01
         DEC +.89517371E+00
ATANT    DEC +.
         DEC +.28647889E+02
         DEC +.29099009E+02
         DEC +.29557117E+02
         DEC +.30022196E+02
         DEC +.30494219E+02
         DEC +.30973143E+02
         DEC +.31458915E+02
         DEC +.31951464E+02
         DEC +.32450706E+02
         DEC +.32956538E+02
         DEC +.33468840E+02
         DEC +.33987474E+02
         DEC +.34512280E+02
         DEC +.35043080E+02
         DEC +.35579670E+02
         DEC +.36121827E+02
         DEC +.36669298E+02
         DEC +.37221809E+02
         DEC +.37779058E+02
         DEC +.38340713E+02
         DEC +.38906417E+02
         DEC +.39475779E+02
         DEC +.40048380E+02
         DEC +.40623768E+02
         DEC +.41201458E+02
         DEC +.41780934E+02
         DEC +.42361643E+02
         DEC +.42943002E+02
         DEC +.43524389E+02
         DEC +.44105151E+02
         DEC +.44684597E+02
         DEC +.45262007E+02
         DEC +.45836623E+02
         DEC +.46407654E+02
         DEC +.46974281E+02
         DEC +.47535651E+02
         DEC +.48090882E+02
         DEC +.48639068E+02
         DEC +.49179276E+02
         DEC +.49710550E+02
         DEC +.50231915E+02
         DEC +.50742380E+02
```

```
         DEC +.51240941E+02
         DEC +.51726583E+02
         DEC +.52198289E+02
         DEC +.52655038E+02
         DEC +.53095816E+02
         DEC +.53519614E+02
         DEC +.53925438E+02
         DEC +.54312314E+02
         DEC +.54679289E+02
         DEC +.55025441E+02
         DEC +.55349884E+02
         DEC +.55651769E+02
         DEC +.55930293E+02
         DEC +.56184703E+02
         DEC +.56414305E+02
         DEC +.56618458E+02
         DEC +.56796589E+02
         DEC +.56948194E+02
         DEC +.57072838E+02
         DEC +.57170160E+02
         DEC +.57239879E+02
         DEC +.57281793E+02
INT      DEC +.57295779E+02
         END

*        FAP
         COUNT    250
         LBL      TRIG,2
         ENTRY    SIN
         ENTRY    COS
COS      UFA      =0233000000132
         TRA      *+2
SIN      UFA      =0233000000000
         STQ      1)
         SXA      BACK,2
         SXA      BACK+1,4
         ANA      =0777777777
         XCA
         CLM
         DVP      =90
         PAX      0,2
         XCA
         ANA      =3
         PAX      0,4
         TQP      *+3
         CLA      NEQ+3,4
         PAX      0,4
         CLA      1)
         SSP
         CAS      =.5
         TRA      INC2
         NOP
OKINT    XCA
```

```
          TRA     Q1,4
          TRA     Q4
          TRA     Q3
          TRA     Q2
Q1        FMP     INT,2
          FAD     SINT,2
          TRA     BACK
Q2        PXD     0,2
          PDC     0,2
          TXI     *+1,2,90
          FMP     INT,2
          CHS
          FAD     SINT,2
          TRA     BACK
Q3        FMP     INT,2
          FAD     SINT,2
          CHS
          TRA     BACK
Q4        PXD     0,2
          PDC     0,2
          TXI     *+1,2,90
          FMP     INT,2
          FSB     SINT,2
BACK      AXT     **,2
          AXT     **,4
          TRA     1,4
INC2      FSB     =1.
          TXI     OKINT,2,1
1)        OCT
NEQ       OCT     1,,3,2
          DEC +.10000000E+01
          DEC +.99984769E+00
          DEC +.99939082E+00
          DEC +.99862953E+00
          DEC +.99756404E+00
          DEC +.99619469E+00
          DEC +.99452189E+00
          DEC +.99254614E+00
          DEC +.99026806E+00
          DEC +.98768833E+00
          DEC +.98480774E+00
          DEC +.98162718E+00
          DEC +.97814759E+00
          DEC +.97437005E+00
          DEC +.97029571E+00
          DEC +.96592582E+00
          DEC +.96126168E+00
          DEC +.95630475E+00
          DEC +.95105651E+00
          DEC +.94551856E+00
          DEC +.93969260E+00
          DEC +.93358042E+00
          DEC +.92718384E+00
          DEC +.92050483E+00
          DEC +.91354545E+00
```

```
DEC +.90630777E+00
DEC +.89879404E+00
DEC +.89100651E+00
DEC +.88294757E+00
DEC +.87461969E+00
DEC +.86602538E+00
DEC +.85716728E+00
DEC +.84804808E+00
DEC +.83867055E+00
DEC +.82903756E+00
DEC +.81915203E+00
DEC +.80901698E+00
DEC +.79863549E+00
DEC +.78801074E+00
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25

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         DEC +.17386877E-01
         DEC +.17410776E-01
         DEC +.17429373E-01
         DEC +.17442660E-01
         DEC +.17450634E-01
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         FAP
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```

```
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         TSX      ASIN,4
         AXT      **,4
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         CHS
         TRA      1,4
ASIN     LAS      =1.
         TRA      EVEN
         TRA      EVEN
         LAS      =.707107
         TRA      *+3
         TRA      LQD
         TRA      LQD
         XCA
         STQ      1)+1
         FMP      1)+1
         CHS
         FAD      =1.
         SXA      *+3,4
         CALL     SQRT
         TSX      LQD,4
         AXT      **,4
         FSB      =90.
         SSP
         LDQ      1)+1
         TQP      *+2
         SSM
         TRA      1,4
LQD      UFA      =0224000000000
         STQ      1)
         SXA      BACK,4
         PAX      0,4
         XCA
         SSP
         CAS      =0171400000000
         TRA      INT4
         NOP
INTOK    XCA
         FMP      INT,4
         FAD      ASINT,4
         LDQ      1)
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         SSM
BACK     AXT      **,4
         TRA      1,4
INT4     FSB      =0172400000000
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EVEN     CLM
         ORA      =90.
         TRA      1,4
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         DEC +.57302922E+02
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```

APPENDIX F
HAND CALCULATION TECHNIQUES

F.1 GENERAL ASSUMPTIONS

Graphical and analytical methods have been employed to compute absorbed planetary and albedo heat fluxes for a two-surface radiator sun-oriented configuration in noon Mars and Venus orbits. Numerical examples are presented for a few extreme and intermediate orbit positions and altitudes in order to facilitate a grasp of the order of magnitude of the heat fluxes to be expected. The hand-calculated numbers are also intended to serve as a check on the computer calculated results.

All symbols used in this appendix, Tables F-1 through F-4, and Figures F-1 through F-11 are defined in Appendix F.8.

In order to account for reflections of thermal radiation, it was necessary to impose the following assumptions and idealizations:

a. The thermal radiation between the planetary radiator surfaces is in diffuse form, i.e., Lambert's Cosine Law is valid (Refs. 1 and 3). For calculation of radiant heat fluxes, the planet, sun, radiator surfaces, and space are treated as a radiation network with $\alpha = \epsilon$.

b. The solar absorptivity and infrared emissivities of the radiator surfaces are assumed to be independent of temperature.

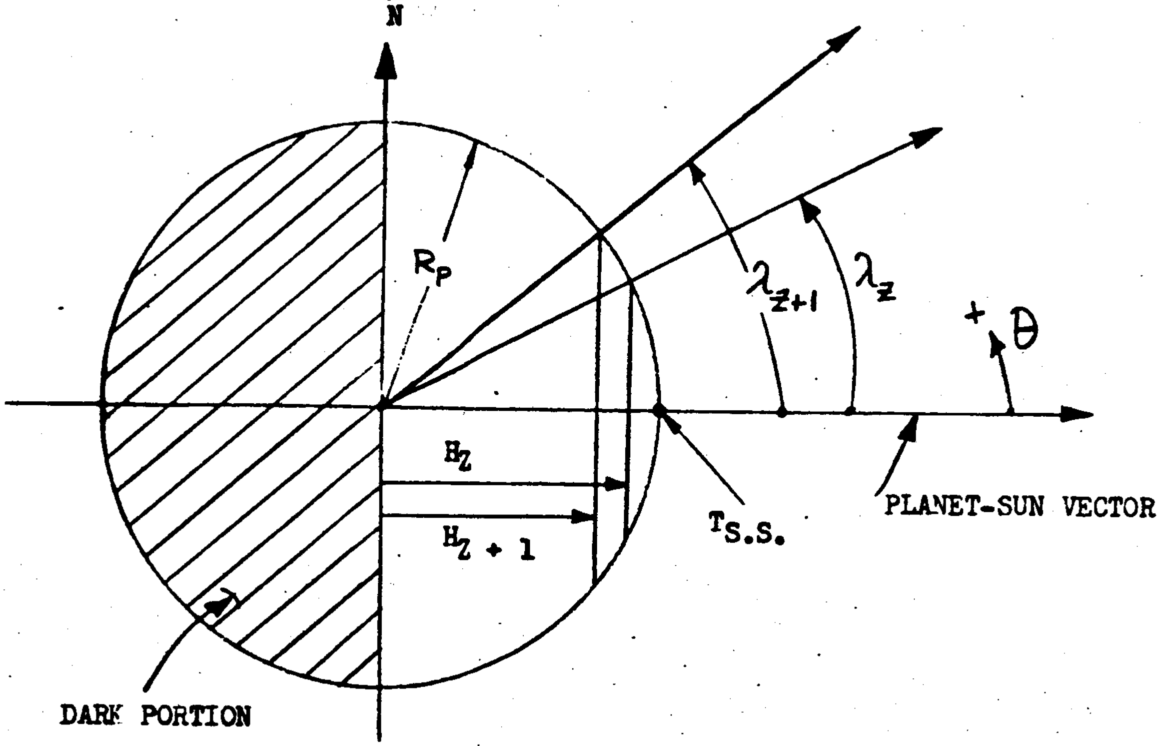
c. For planetary heat flux calculations, the planet, sun, and space are treated as black bodies.

d. The planet surface temperature is assumed to have a cosine variation as shown in Fig. F-1.

Although it is realized that for ϵ values approached 0.20 or less, specular thermal radiation should be accounted for, assumption a. will still be used for the heat flux calculation mainly because of the lack of accurate analytical models and experimental data. The above assumptions will give a first approximation on heat flux magnitudes which include reflections between adjacent surfaces.

F.2 RADIATOR SURFACE CONFIGURATION FOR HAND CALCULATIONS

Computation of absorbed solar, albedo, and planetary heat fluxes on orbiting radiator surfaces usually requires the aid of digital computer numerical solutions. The main difficulty arises from the fact that for most cases, the configuration factor equations are not easily integrable in closed from. It was, therefore, decided to use the simplest possible radiator surface configuration as the basis for the hand calculations and to investigate only extreme and intermediate values of h and θ. A noon



$T_Z = T_{D.S.} + (T_{S.S.} - T_{D.S.}) \cos \lambda_Z, \; -90^\circ \leq \lambda \leq +90^\circ$

SUBSCRIPT: Z = Zone number

$T_{S.S.}$ = Planet surface temperature @ sub-solar point

$T_{D.S.}$ = Planet surface temperature of dark-side portion

λ_{Z+1}, λ_Z = Direction of outward normal from planet surface

H_Z = Height of spherical zone formed by angle $2\lambda_Z$

A_{PZ} = Surface area of spherical zone = $2\pi R_P (H_Z - H_{Z+1})$

Fig. F-1 Planet Node Breakdown and Temperature Assumption for Mars Noon Orbit

orbit and sun-oriented two-equal-surface-area radiator system was selected. The pertinent cases, geometry, and dimensions are listed in Table F-1. Surface 1 refers to the primary radiator surface and surface 2 to the adjacent secondary radiator surface. For the radiator configuration in Table F-1, there is no direct solar heat flux term.

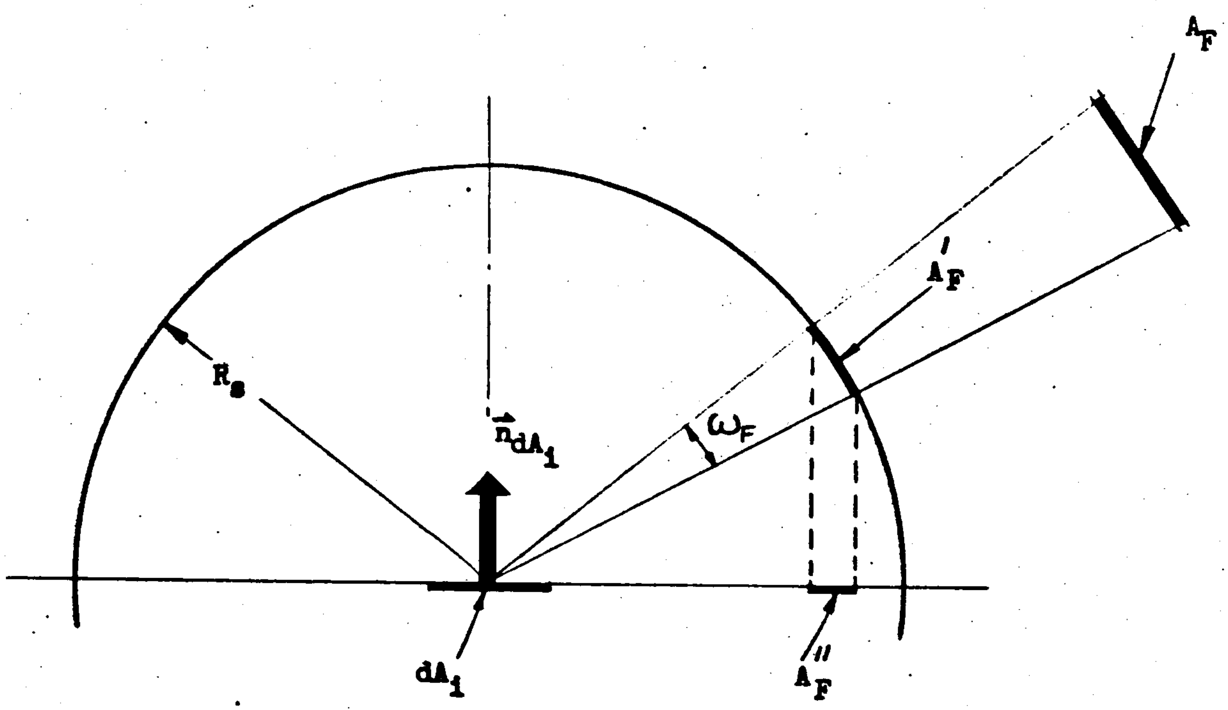
F.3 CALCULATION OF GEOMETRIC CONFIGURATION FACTORS

The analysis of the radiant energy exchange between a pair of diffuse radiating surfaces requires evaluation of the geometric configuration factor between the surfaces. Although values have been tabulated in the literature for a multitude of configurations, the present problem is compounded further by the fact that the view of the planet surface from one radiator surface may be obstructed by an adjacent radiator surface. For this reason, it was decided to employ a graphical technique commonly denoted (Refs. 1, 2, and 3) as the "unit sphere" or "double area projection method" for the calculation of $F_{(i)(j)}$ values. This type of graphical construction is demonstrated in Fig. F-2; the deriviation of the equation 1 is presented in Ref. 2 (Appendix F.7). It is convenient for discussion purposes to group the $F_{(i)(j)}$ calculation methods into the following cases:

Case 1: Radiator surface to radiator surface with no shading.

Case 2: Radiator surface to planet surface with shading

Case 3: Planet surface to sun.



A_F = Finite area (any irregular shape) in question

dA_i = Surface element

$\vec{n}_{dA_i}$ = Unit normal of surface element

R_s = Radius of ficticious sphere

A'_F = Area subtended on surface of sphere R_s by solid angle ω_F

ω_F = Solid angle subtended at dA_i by A_F

A''_F = Normal projection of A'_F onto base dA_i

$F_{(dA_i)(A_F)} = A''_F / \pi R_s^2$ .... (1)

Fig. F-2 Determination of Geometric Configuration Factor by Double Projection Method

a. <u>Case 1</u>. Evaluation of the quantity $F_{(1)(2)}$ is determined from Fig. 24 of Ref. 2. For the dimensions and radiator surface configuration selected for the hand-calculation analysis, this value is computed to be $F_{(1)(2)} = F_{(2)(1)} = 0.20$.

b. <u>Case 2</u>. To account for the variation of shading effects for each point of the primary and radiator surfaces, each surface was broken down into 16 equal elemental areas, with $A_1 = A_2 = 1$ Ft.^{2}, $a = b = c = 1$ Ft. and $dA_i = 1/16$ Ft.^{2} for $i = 1 - 16$. If a reference sphere of radius R_s is then constructed about dA_{i2} and A_1, surface 1 acts as an obstruction to the view of dA_{i2} to the planet surface. The amount of obstruction or shading effect from surface 1 is dependent on the orbit position, altitude, and orientation of the radiator surfaces. However, a general shading curve, which is independent of h and θ, can be determined for each elemental area as illustrated by the double projection method of Fig. F-3. For equal dimensions, the same shading curves are obtained if one considers an elemental dA_{i1} shaded by A_2.

The procedure for computation of the geometric configuration factors is described by the steps listed below:

1. For each dA_i, calculate enough points (d_{ji}, δ_{ji}) from the equations of Fig. F-3 in order to determine the shape of the general shading curve. Plot these points to a suitable scale.

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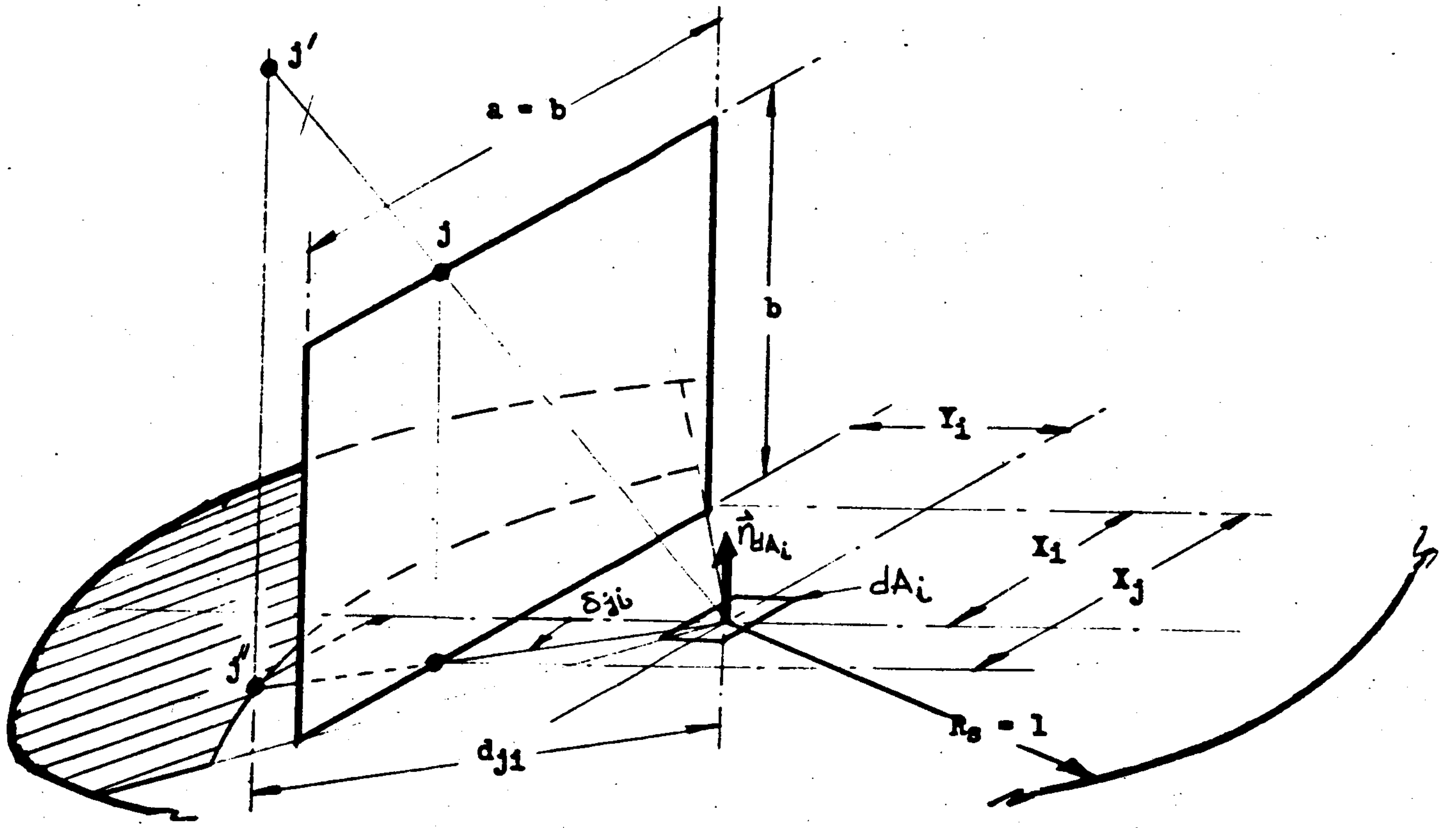


EQUATIONS FOR LOCATING DOUBLE-PRIMED POINTS:

$$d_{ji} = (1) \cos\left[\tan^{-1}\left(b/ \sqrt{(X_j-X_i)^2 + Y_i^2}\right)\right]$$

$$\delta_{ji} = \cos^{-1}\left(Y_i/ \sqrt{(X_j-X_i)^2 + Y_i^2}\right)$$

NOTATIONS:

Subscript i = element number
Subscript j = point on shading surface
Subscript j' = projected point j onto unit sphere surface
Subscript j" = projection of point j onto base plane of elemental area dA_i
n_{dA_i} = outward unit normal of dA_i
R_s = Radius of unit sphere = 1 unit
a, b, X, Y = geometric dimensions as defined

Fig. F-3 Determination of Points for Shading Areas Between Radiator Element and Adjacent Radiator Surface

2. Determine the shape of the area of the planet surface onto the base of the sphere R_s for the case of no shading for each orbit position and altitude studied using the same scale of Step 1.

3. Superimpose, with proper regard to orientation of radiator surfaces with respect to the planet, on the curves obtained from Step 2 the curves of Step 1.

4. Measure the unshaded areas from Step 3. The differential configuration factor is then computed by dividing these unshaded area values by πR_s^2.

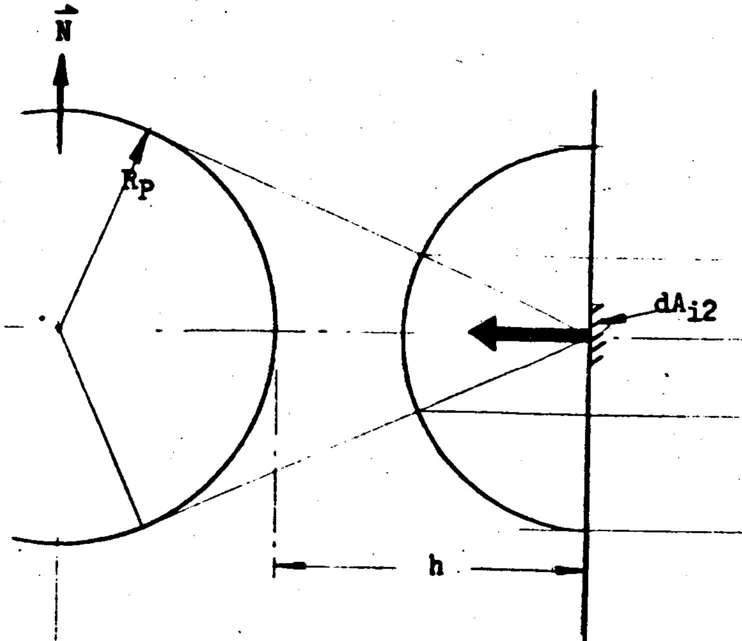
5. The finite-finite configuration factors $F_{(1)(P)}$ and $F_{(2)(P)}$ are then computed from the following area-averaged configuration factor equation:

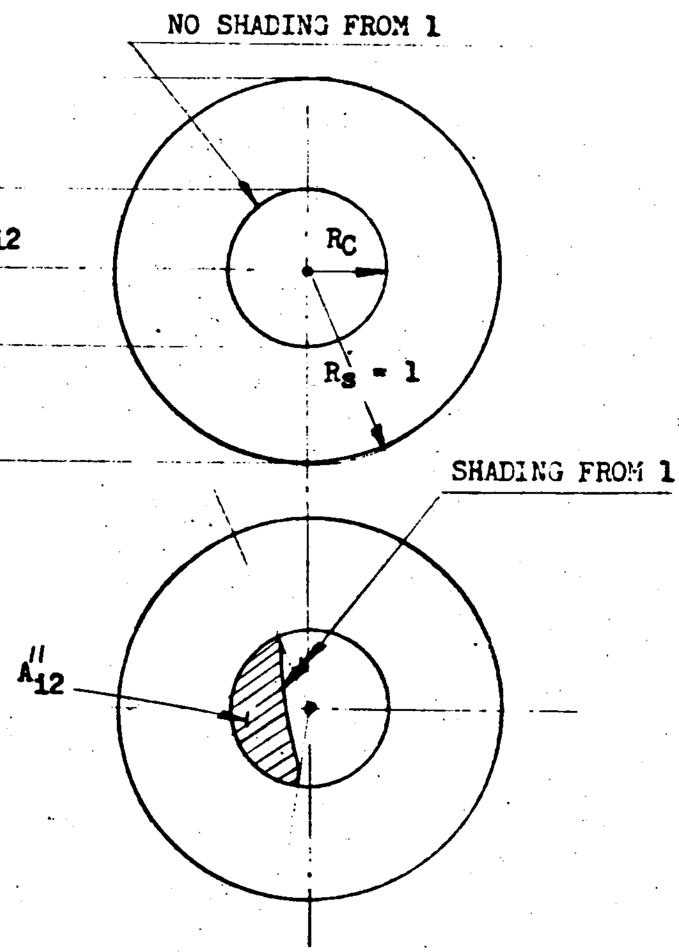
$$F_{(m)(p)} = 1/(A_m) \sum_{i=1}^{16} A dA_{im} \, F_{(dA_{im})(p)}, \qquad m = 1, 2$$

Figures F-3 through F-11 illustrate steps 1, 2, and 3 in detail. For the actual plotting of points, a scale of 1 cm = 1000 KM was used.

Circular areas and segments of circles represent the projected areas of the visible planet surfaces onto the base plane of the element dA_{im} for the case of no shading and for $\theta = 0°$ and $90°$. Two conditions prevail for $\theta = 45°$ (Refer to Fig. F-5):

SURFACE 2:



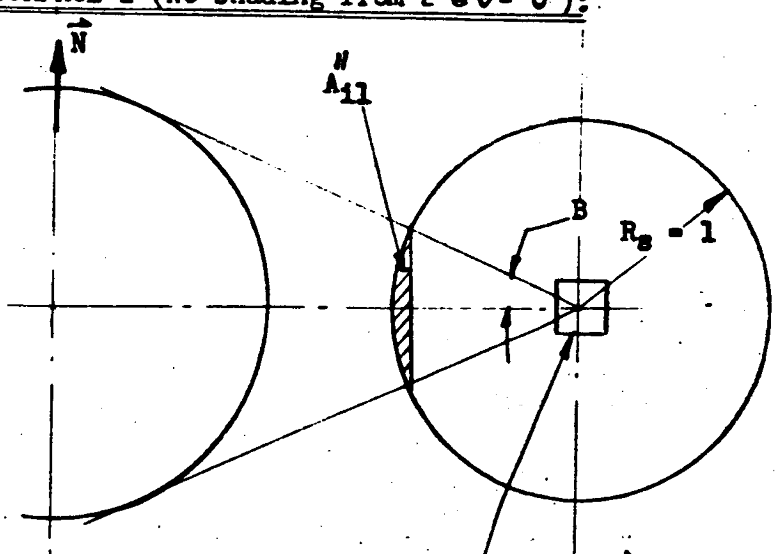


For shading calculations:

$$F_{(dA_{12})(P)} = \frac{\pi R_C^2 - A''_{12}}{\pi (1)^2}$$

$$R_C = (1)\, R_P/(R_P + h)$$

SURFACE 1 (No shading from 2 @ $\theta = 0^\circ$):



dA_{i1}, normal $\vec{n}_{dA_{i1}}$ into the plane of paper

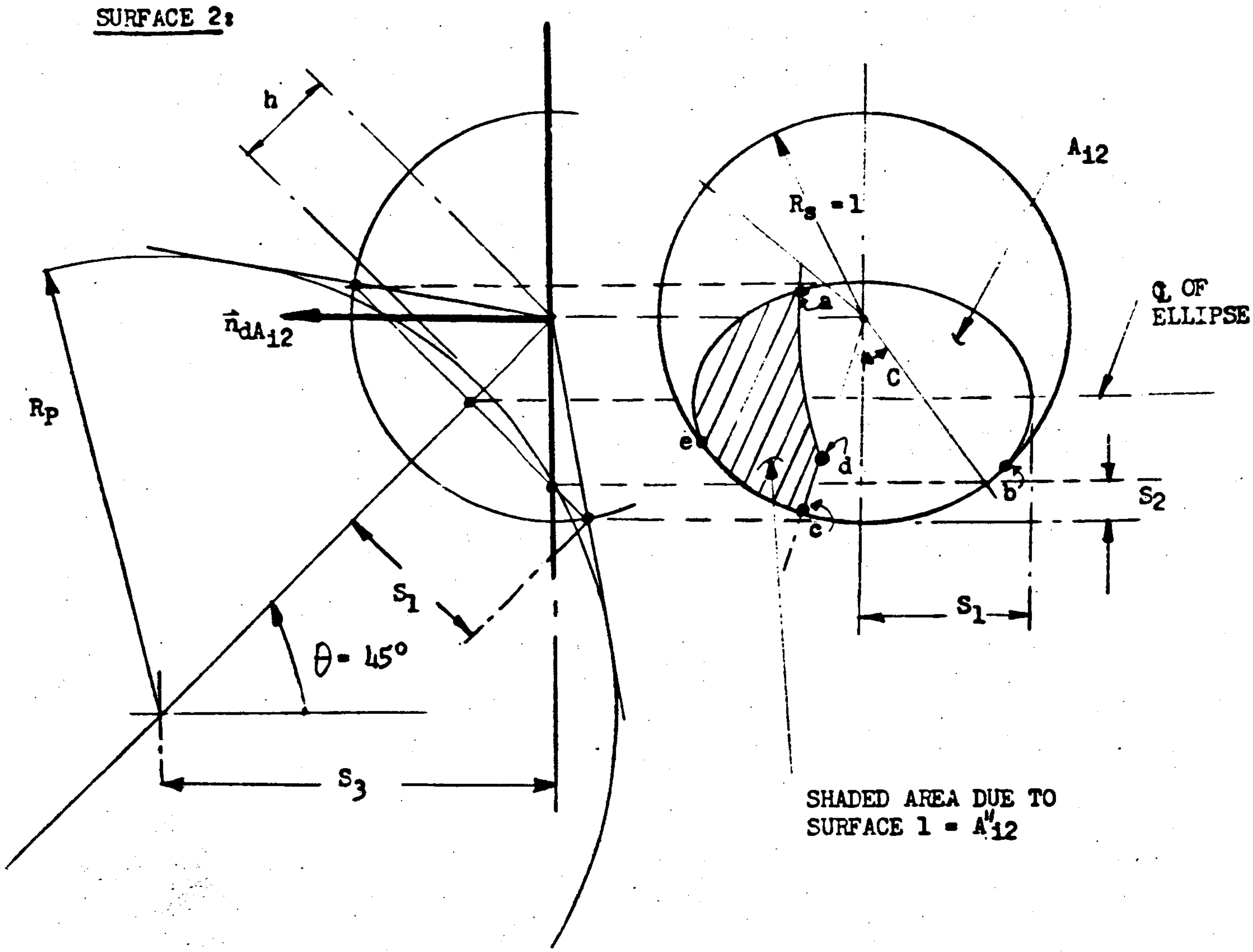
$$F_{(dA_{i1})(P)} = A''_{i1}/\pi (1)^2$$

$$A''_{i1} = \tfrac{1}{2} (1)^2 (2B - \sin 2B)$$

$$B = \sin^{-1} (m)$$

$$m = R_P/(R_p + h)$$

Fig. F-4 Determination of Configuration Factor $F_{(dA_i)(P)}$ for $\theta = 0^\circ$, Venus Orbit



S_1 = Semi-major axis of ellipse

S_2 = Height of circular segment of half-angle C

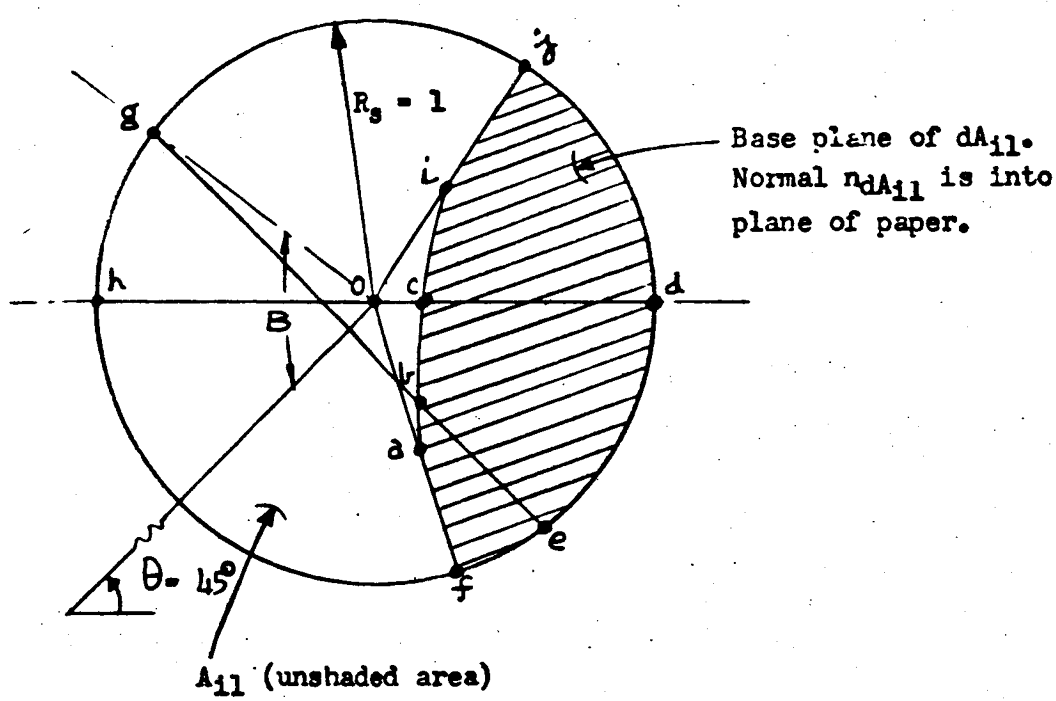
S_3 = Distance from plane of dA_{12} to planet center.
For $S_3 > R_p$: $S_2 = 0$.

$A_{12} = A_{abcea}$, $A''_{12} = A_{adcea}$

$$F_{(dA_{12})(P)} = \frac{A_{12} - A''_{12}}{\pi(1)^2}$$

Fig. F-5 Determination of Configuration Factor $F_{(dA_i)(P)}$ for $\theta = 45°$, Venus Noon Orbit

SURFACE 1:



$$F_{(dA_{i1})(P)} = \frac{A_{i1} - A''_{i1}}{\pi (1)^2}$$

$$B = \sin^{-1} (R_p/(R_p + h))$$

For $\theta = 90^\circ, 0^\circ$: $A''_{i1} = A_{cdefabc}$

$A_{i1} = A_{hocdefh}$

For $\theta = 45^\circ$: $A''_{i1} = A_{befab}$

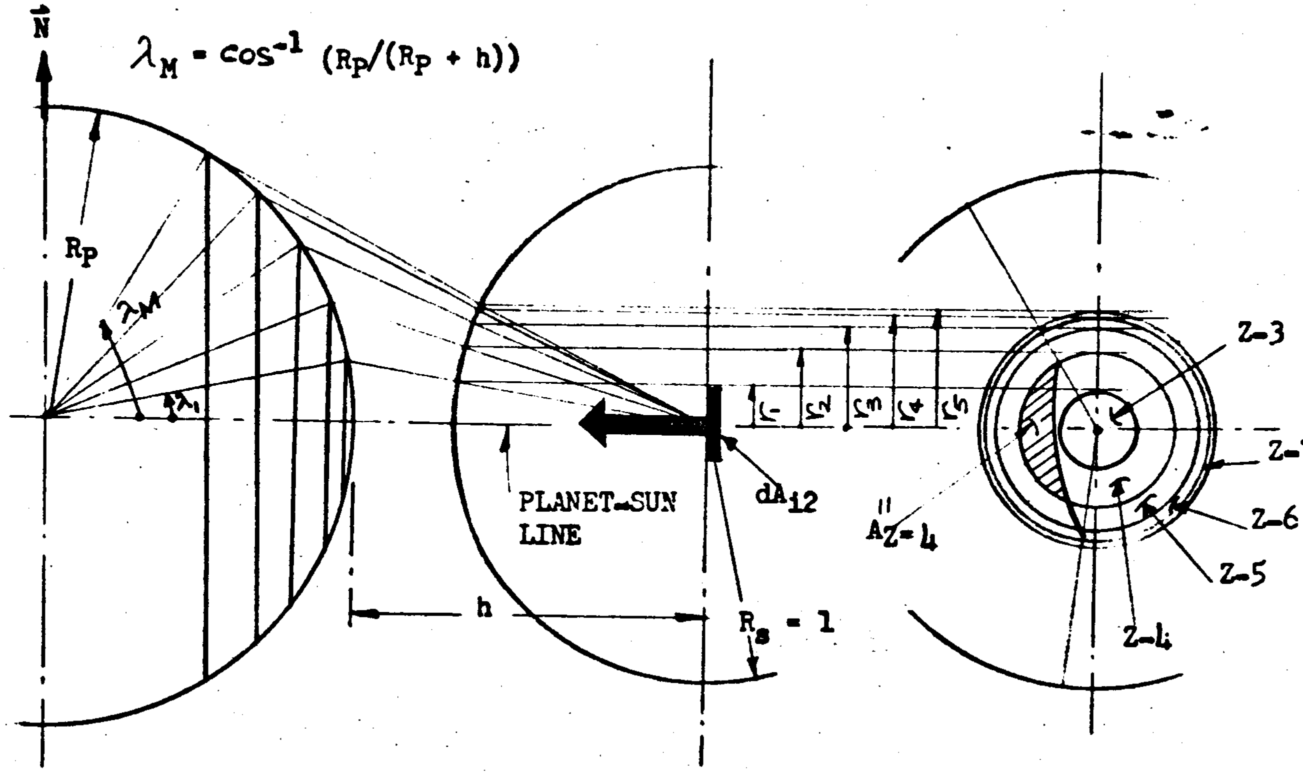
$A_{i1} = A_{gbefhg}$

A''_{i1} = Shaded area due to surface 2 for $\theta = 0^\circ$, or 45° calculation

$A_{ijdefabci}$ = Total shaded area as determined from Figure F.3

Fig. F-6 Determination of Configuration Factor $F_{(dA_1)(P)}$ for $\theta = 90^\circ, 45^\circ, 0^\circ$, Venus Noon Orbit

SURFACE 2:



A''_{12z} = Shaded area due to Surface 1

$A''_{Z=4}$ = "Shown only for Zone #4"

λ_Z = Direction of outward normal of spherical zone Z measured from planet-sun line

Φ_Z = Angle measured from planet-sun line as defined

r_Z = Radius of projected zone onto surface of R_s

R_P = Planet radius

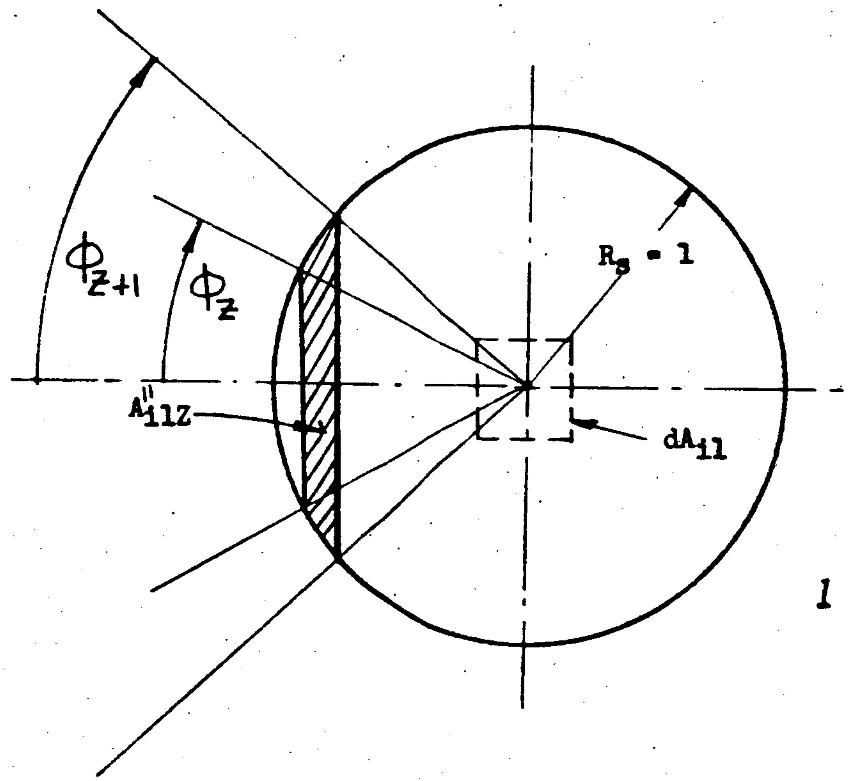
h = Altitude

Subscript Z = refers to zone number

$$F_{(dA_{12})(Z)} = (\pi r^2_Z - A''_{12Z})/\pi$$

Fig. F-7 Planet Node Breakdown for $F_{(dA_i)(Z)}$ Calculation, h = 3000 KM, $\theta = 0^\circ$, Mars Noon Orbit

SURFACE 1: (No shading from Surface 2)



1 UNIT = 1000 KM

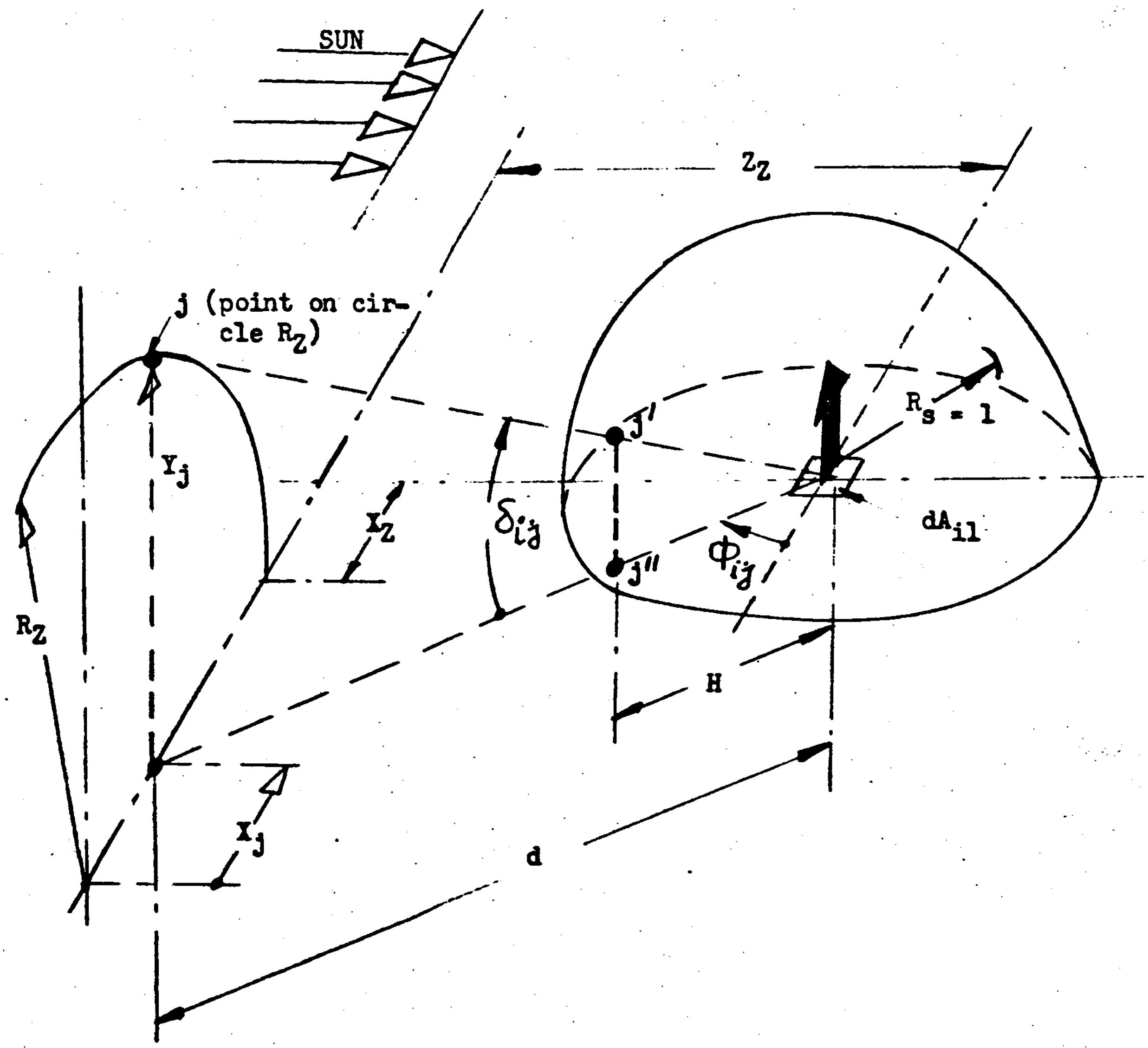
$$F_{(dA_{11})(Z)} = A''_{11Z}/\pi$$

$$A''_{11Z} = \tfrac{1}{2}\left[(2\Phi_{Z+1} - \sin 2\Phi_{Z+1}) - (2\Phi_Z - \sin 2\Phi_Z)\right]$$

λ_Z (°)	Z #	Φ_Z (°)	A_{PZ}, 10^{14} Ft^2	r_Z, UNITS	T_Z, °R
0	3	12.9	0.0450	2.18	540
11.6	4	22.6	0.1372	3.81	531
23.2	5	28.5	0.2180	4.72	516
34.8	6	31.4	0.297	5.18	496
46.4	7	32.0	0.360	5.29	470
58.0					

Fig. F-7 (Continued)

(a) Determination of Projected Points j'':



EQUATIONS:

$$X_j^2 + Y_j^2 = R_Z^2$$

$$\tan \phi_{ij} = Z_Z/(R_Z - X_j + X_Z)$$

$$d = Z_Z/\sin(\phi_{ij})$$

$$\tan \delta_{ij} = Y_j/d$$

$$H = (1) \cos \delta_{ij}$$

Fig. F-8 Double Projection Method for Determination of $F_{(dA_{i1})(Z)}$ for $\theta = 90°$, Mars Noon Orbit

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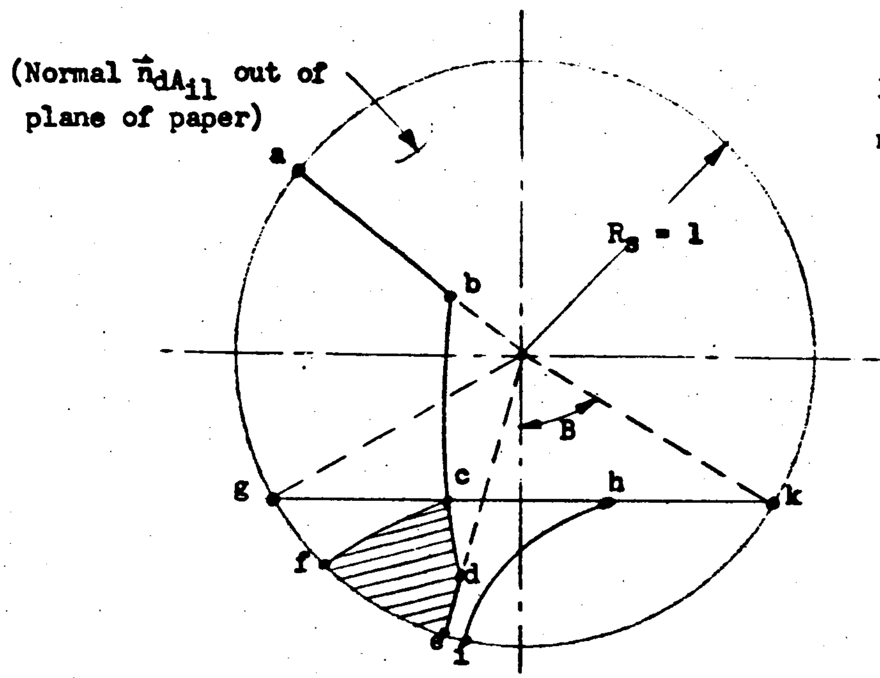
(b) CALCULATION OF $F_{(dA_{i1})}(Z)$



$B = \sin^{-1}(m)$

$m = R_p/(R_p + h)$

① = A''_{fchief} = Projected area of zone Z for which $\lambda_Z \leq \lambda \leq \lambda_{Z+1}$. The curves fc and ih are locus of projected points for the zones formed by λ_Z and λ_{Z+1} respectively.

$A''_{abcdefga}$ = General shading curve due to surface 2.

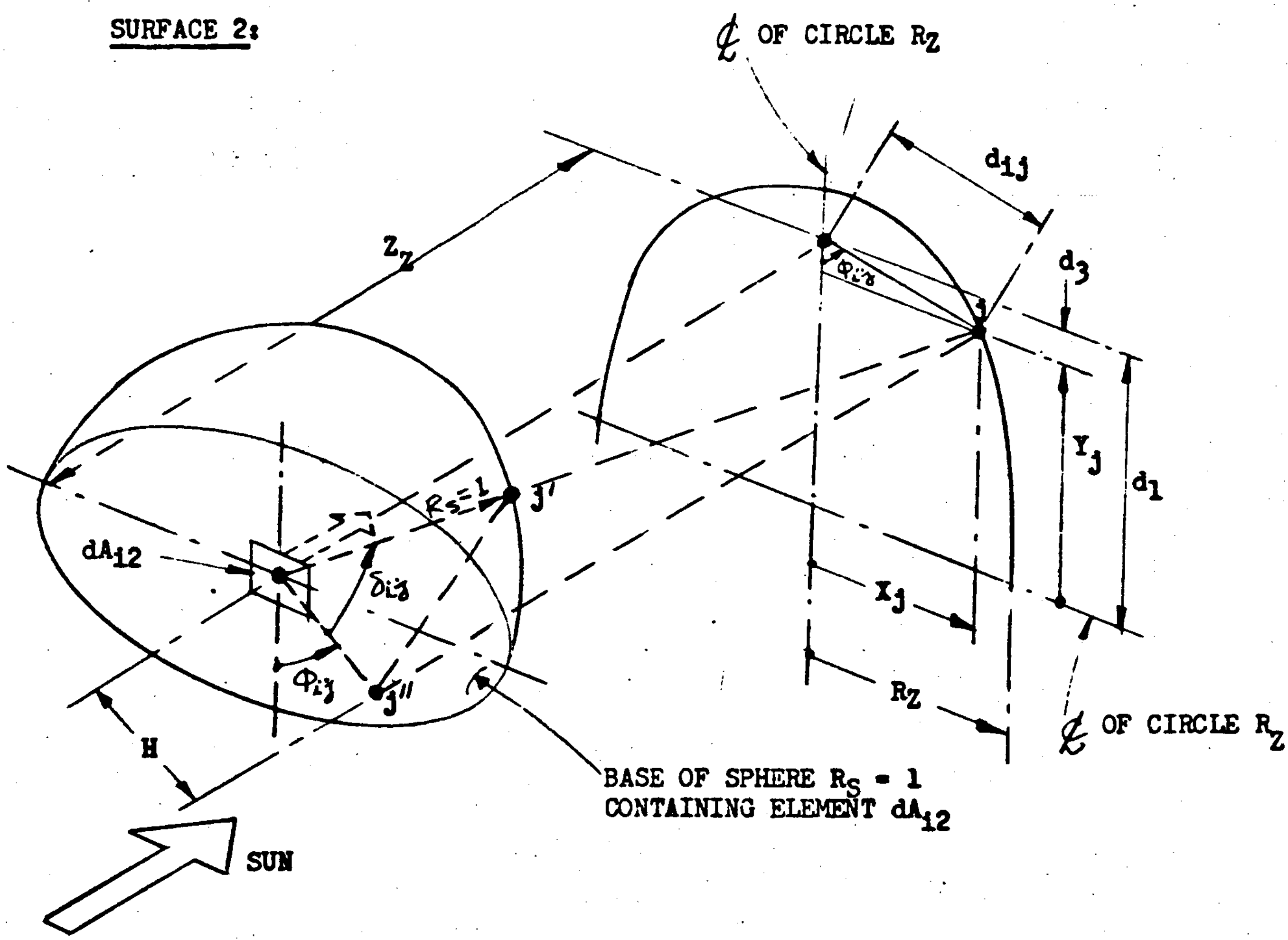
② = A''_{cdefc} = Shaded portion due to surface 2 onto zone Z.

$A''_{gchkiefg}$ = Projected area of entire visible portion of planet surface.

$F_{(dA_{i1})}(Z) = A''_{chiedc}/\pi = (① - ②)/\pi$

Fig. F-8 (Continued)

SURFACE 2:



EQUATIONS:

$$X_j^2 + Y_j^2 = R_Z^2$$

$$\tan \phi_{ij} = X_j/(d_1 - Y_j)$$

$$d_1 = (R_P + h) \sin \theta$$

$$d_{ij} = X_j/\sin \phi_{ij}$$

$$\tan \delta_{ij} = Z_Z/d_{ij}$$

$$H = (1) \cos \delta_{ij}$$

For examples of shading curves, consult Figures F-10–F-11.

Fig. F-9 Double Projection Method for Determination of $F_{(dA_{12})(Z)}$ for $\theta = 45^\circ$, Mars Noon Orbit

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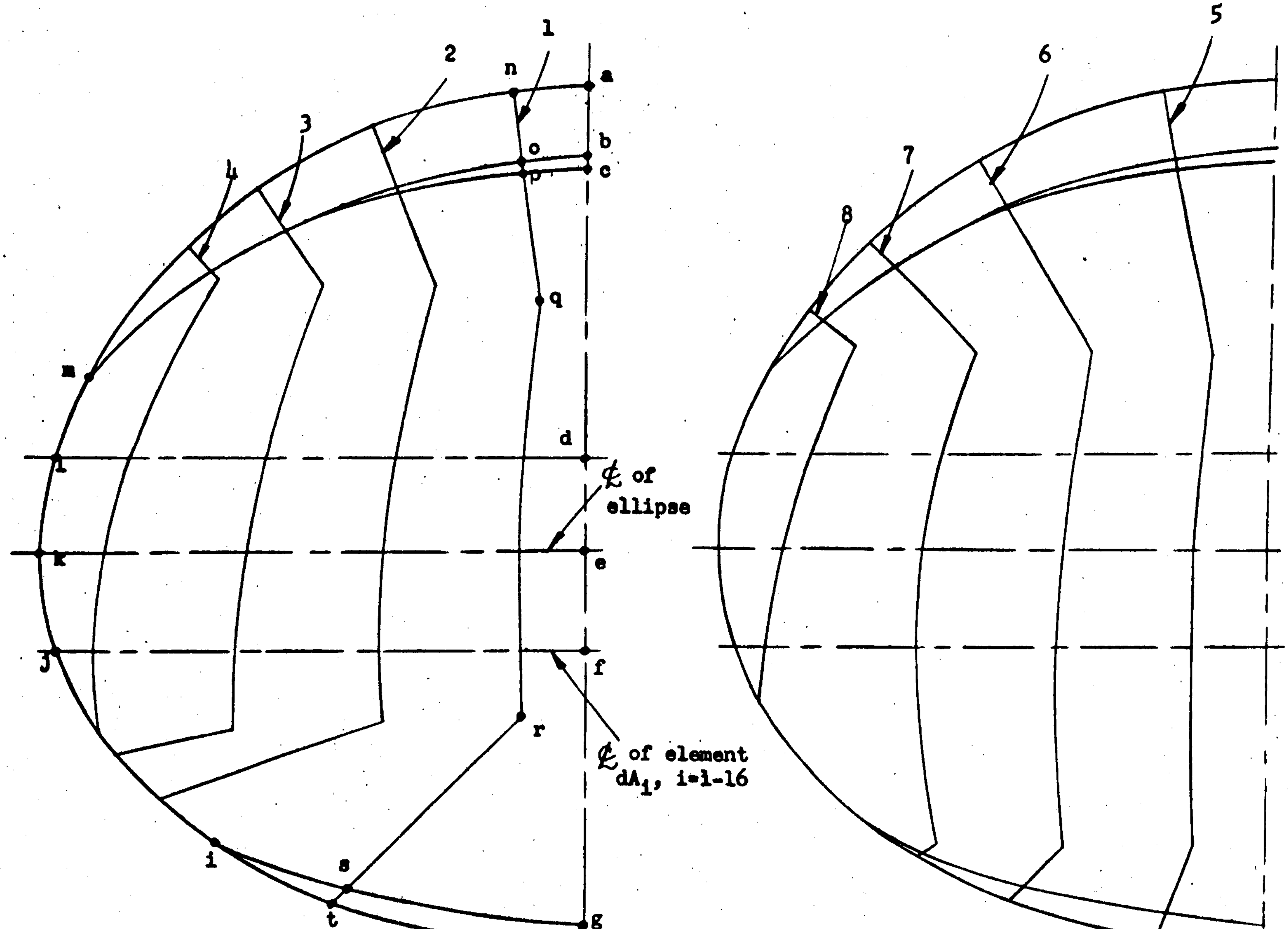


SCALE: 1 cm = 1000 km

Fig. F-10 Shading Curves for Case 12, Surface 2

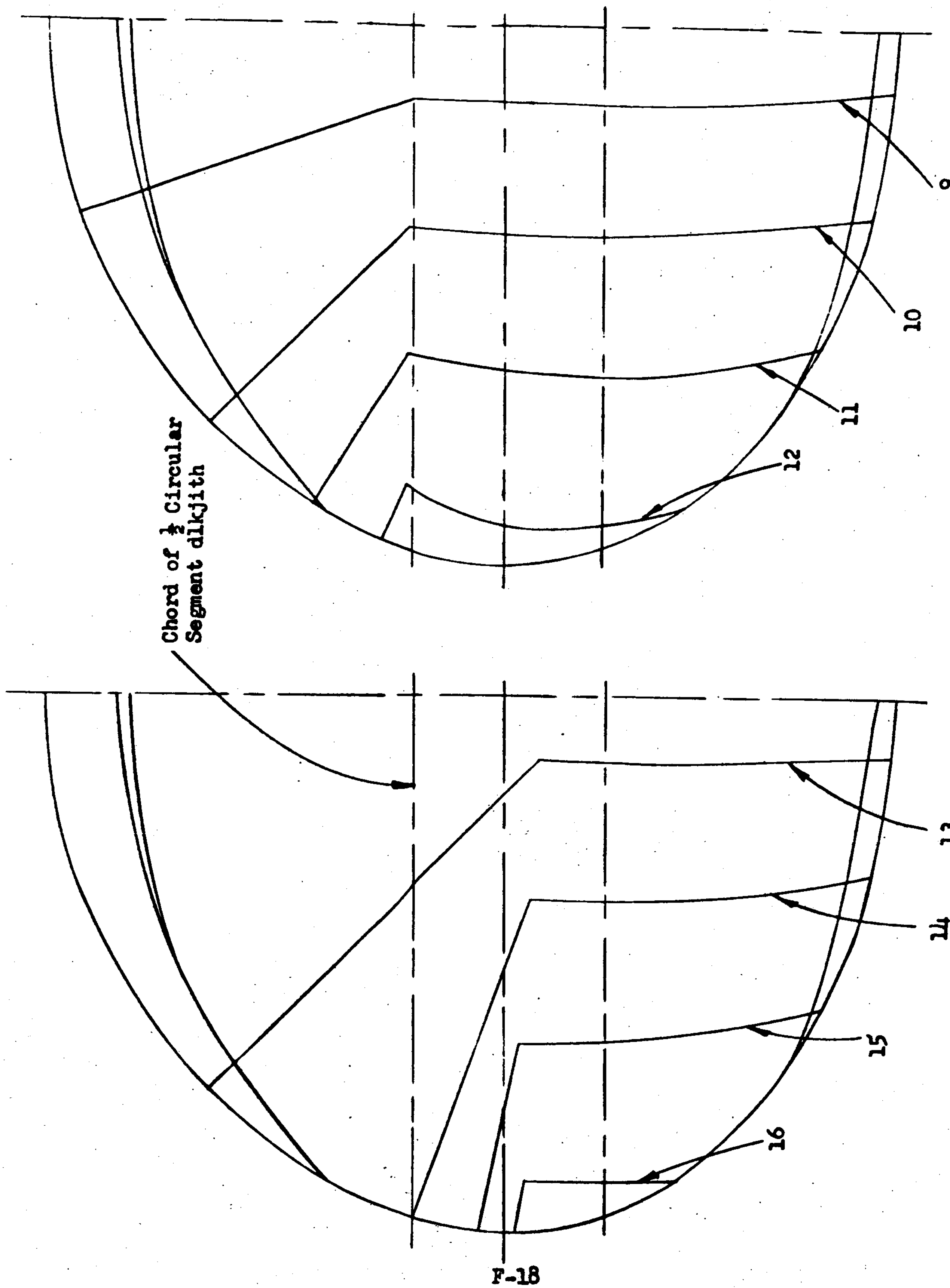
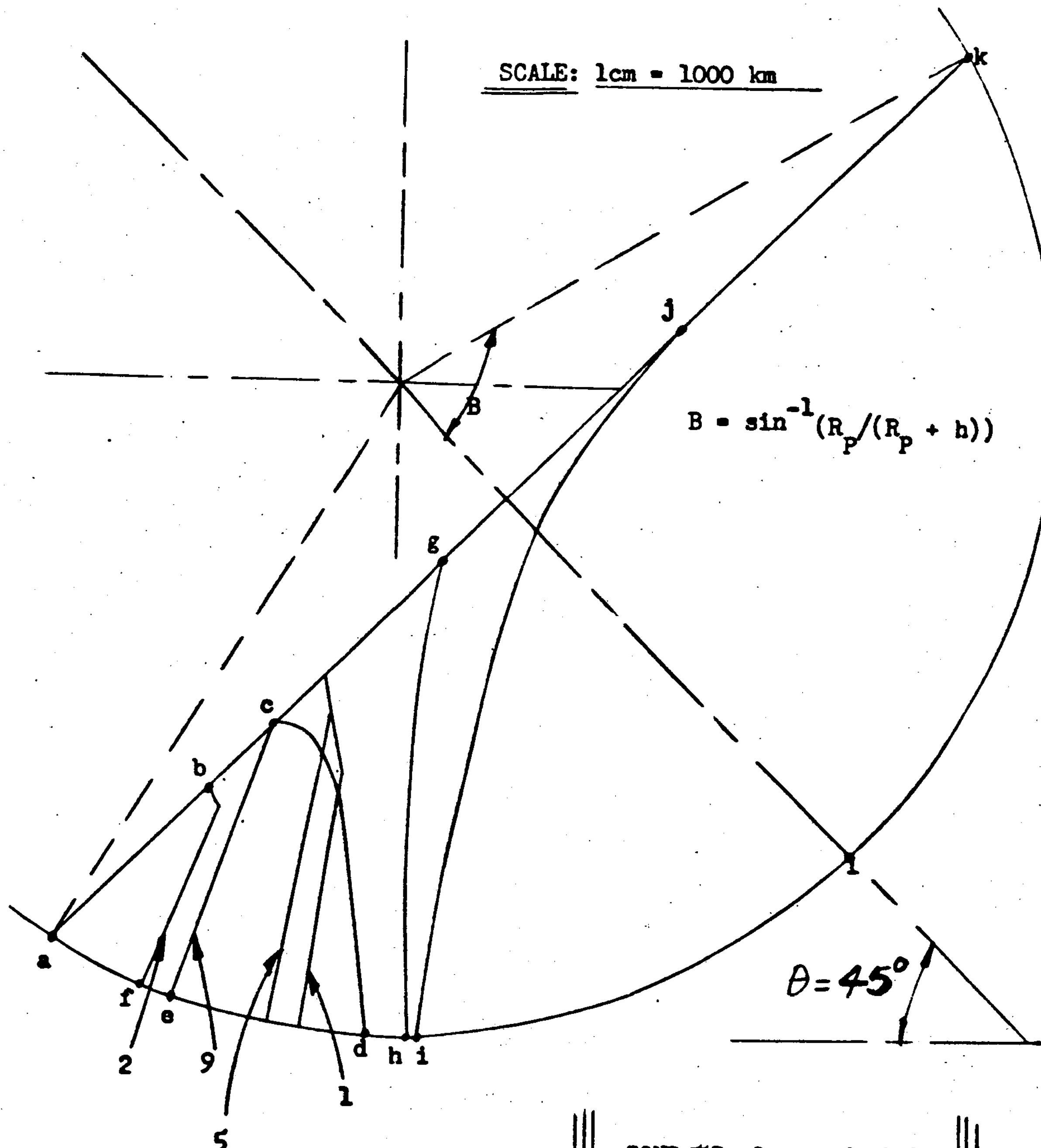


Fig. F-10 (Continued)



ZONE #3:	Curve abcdefa
ZONE #4:	Curve cdhgc
ZONE #5:	Curve ghijg
ZONE #6:	Curve jklij

NOTE: No shading for element number $i = 3, 4, 6\text{-}8$, and 10-16.

Fig. F-11 Shading Curves for Case 12, Surface 1

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(a) $S_3 < R_P$: projected area = $\frac{1}{2}$ (ellipse area) + segment of ellipse + segment of circle = A_{abcda}.

(b) $S_2 < R_P$: (entire planet surface visible): projected area = area of ellipse.

The projections of the planet surfaces (step 2) are the same for all elements since the planetary and altitude dimensions are much greater than the radiator dimensions.

The calculated configuration factors for the cases studied are tabulated in Table F-2.

c. Case 3. Geometric configuration factors from the planet surface under consideration to the sun are required for the albedo heat flux computation. The F_{PS} values were calculated by the "unit sphere" method, and the numerical results are listed in Table F-3.

F.4 COMMENTS ON FIGURES ILLUSTRATING DOUBLE PROJECTION METHODS

As mentioned previously, computation of the geometric configuration factor to account for shading is best accomplished for our particular case by the method of "double projection." However, it turns out that even this method is quite time-consuming, and involves laborious numerical calculations, graphical construction, and planimeter measurements. The step-by-step process involved here is illustrated in Figs. F-3 through F-11 for the different θ' and h altitude cases investigated.

The dark arrow shown in each figure represents the unit normal of the element dA_{i1} or dA_{i2}, and is assumed to be located at the center of the element. For reference purposes only, the arrow labeled as $\vec{N}$, e.g. Figs. F-1, F-4, F-7 represent the north pole of the planet, and lies in the orbit plane formed by the $\vec{N}$ and planet-sun vector.

Equations for configuration factor calculation from the element to a zone of mars are also presented in Figs. F-7 through F-11. For Figs. F-4 through F-7, the projected planet areas onto the base plane of the reference sphere R_s was accomplished with a scale of 1 cm = 1000 KM.

For the Mars zone breakdown at $\theta = 45°$ and 90°, the points j'' were located by computing H and φ_{ij} values for several X_j values. Distances, such as R_Z and Z_Z were measured from graphical construction for a given λ_Z value, thus, resulting in a combination graphical and trigonometric calculation technique for locating the points j''. Since the loci of the points j'' are bounded by the projection curves of the entire visible planet surfaces, the H, φ_{ij} values are then superimposed onto the visible area curve. The projected area of each zone is then the area bounded by λ_Z, λ_{Z+1} and the visible area curves.

F.5 CALCULATION OF RADIANT HEAT FLUXES

Poljak's net radiation method for an enclosure of diffuse radiating surfaces was used to calculate the radiant interchange factors K_P, K_{ST} discussed in Ref. 3 (Appendix F.7). These "K" factors physically account for absorptions and reflections between adjacent radiator surfaces and planet surfaces. The net radiation equations, as presented in Ref. 1 (Appendix F.7) have been programmed in matrix form suitable for digital computer solution.

Since Poljak's equations require solution of n simultaneous algebraic equations in n unknowns, the existing LMSC program, entitled RADK, was used for the actual numerical calculations of the K factors. The input to the RADK program consisted of the following steps:

a. Input all required configuration factors and surface areas.

b. To obtain K_P values, input infrared emissivities of radiator surfaces and set emissivity of planet, sun, and space = 1.

c. To obtain K_{ST} values, input solar absorptivities of radiator surfaces and set the emissivities of the sun-lit portions of the planet surface equal to $1 - \rho_p$. For those portions of the planet which lie in the sun's shade, set the emissivity = 1. The radiant heat fluxes are then computed from the following equations:

$$q_{mp} = \sum_{p} K_{mp} \sigma T_p^4 ; \; m = 1, 2 \quad . \; . \; . \; . \; (A)$$

$$q_{mst} = K_{mst} \sigma T_S^4 \; (q_{msd} \text{ (direct solar = 0))} \quad . \; . \; . \; (B)$$

For all θ and h values, the entire visible portion of the planet Venus as seen from a radiator element was taken as one constant temperature node at 235°K. Table F-4 presents a compilation of the planetary and temperature data used in equations A and B. A list of the planet node breakdown for the Mars hand calculation studies is given in Table F-5.

To account for variations of temperature over the surface of Mars, the planet was divided into various constant temperature nodes or spherical zones. For those cases in which the subtended angle $2\lambda_Z$ was greater than 15°, the zone breakdown is shown in Fig. F-8 and F-9. An average temperature was assumed for the hand calculations. This average value was computed from the equation of Fig. F-1 at a λ value of $(\lambda_Z + \lambda_{Z+1})/2$.

Further idealizations were introduced into the Mars hand calculation study. For example, the temperatures calculated at the $\lambda = 0°$ and 45° points were assumed in equation A for an altitude of 30,000 KM. Because the subtended angle λ_m for h = 100 KM was less than 15°, the entire visible portion of the planet was also taken as one zone for the planetary heat flux calculations.

No zone breakdown is required for the planet Venus since the data of Table F-4 indicates a uniform temperature over the entire planet surface.

Appendix F.6 contains a sample numerical calculation for Case 12 and demonstrates the application of the methods discussed in the preceeding sections.

F.6 HEAT FLUX HAND-CALCULATION FOR CASE 12

Element Breakdown

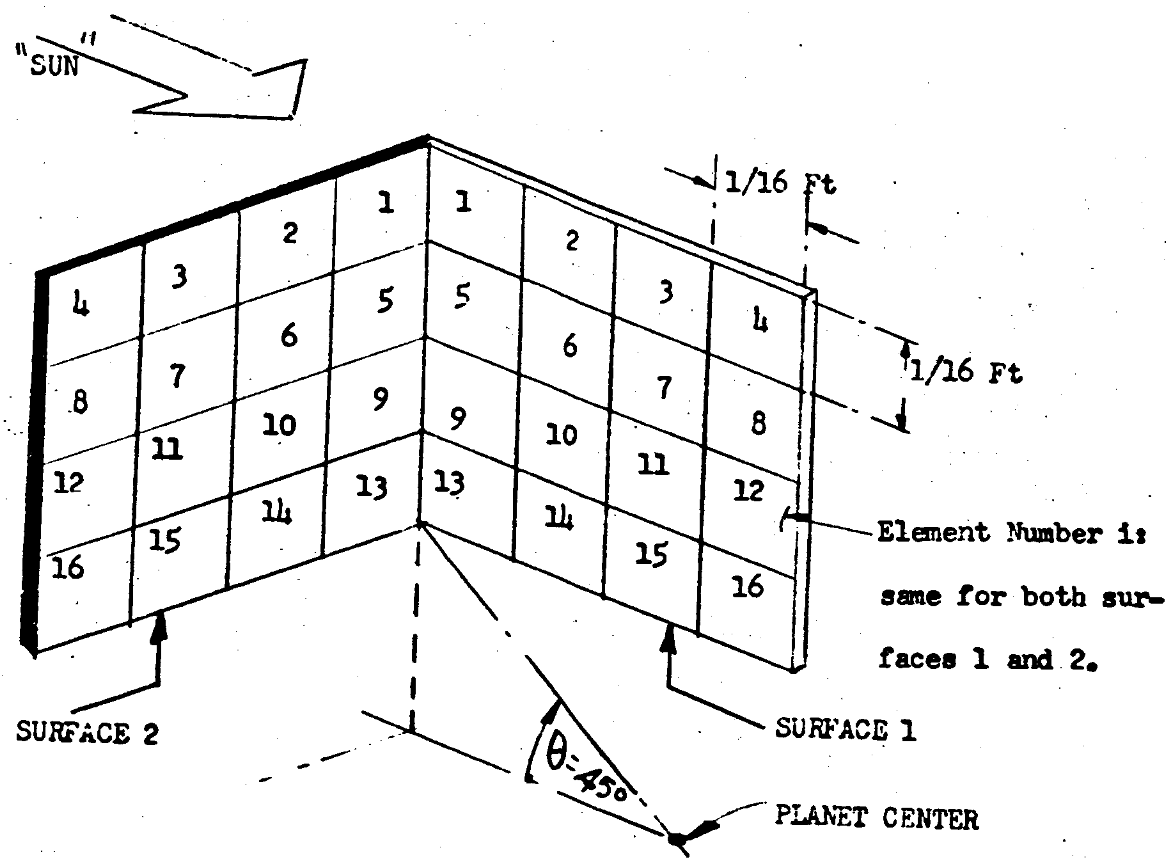

Table F-1

TABULAR SUMMARY OF RADIANT HEAT FLUX HAND-CALCULATED RESULTS

All tabulated results are restricted to following conditions:

CASE NO.	ORBIT	CONFIGURATION	RADIATOR DIMENSIONS	$\left(\frac{\alpha_s}{\epsilon}\right)_1$	$\left(\frac{\alpha_s}{\epsilon}\right)_2$
1-20	NOON-ORBIT	SUN-ORIENTATION	a/b = 1 c/b = 1 ϕ = 90° α = 90° β = 90°	0.25/0.85	0.96/0.90
21				0.3/0.3	0.2/0.04
22		PLANET-ORIENTATION		0.25/0.85	0.96/0.90

FURTHER NOTES:

1. Subscript 1 = Primary Radiator Surface
2. Subscript 2 = Secondary Radiator Surface
3. θ = orbit position, h = altitude, α_s = solar absorptivity. ϵ = Emissivity.
   q = heat flux.

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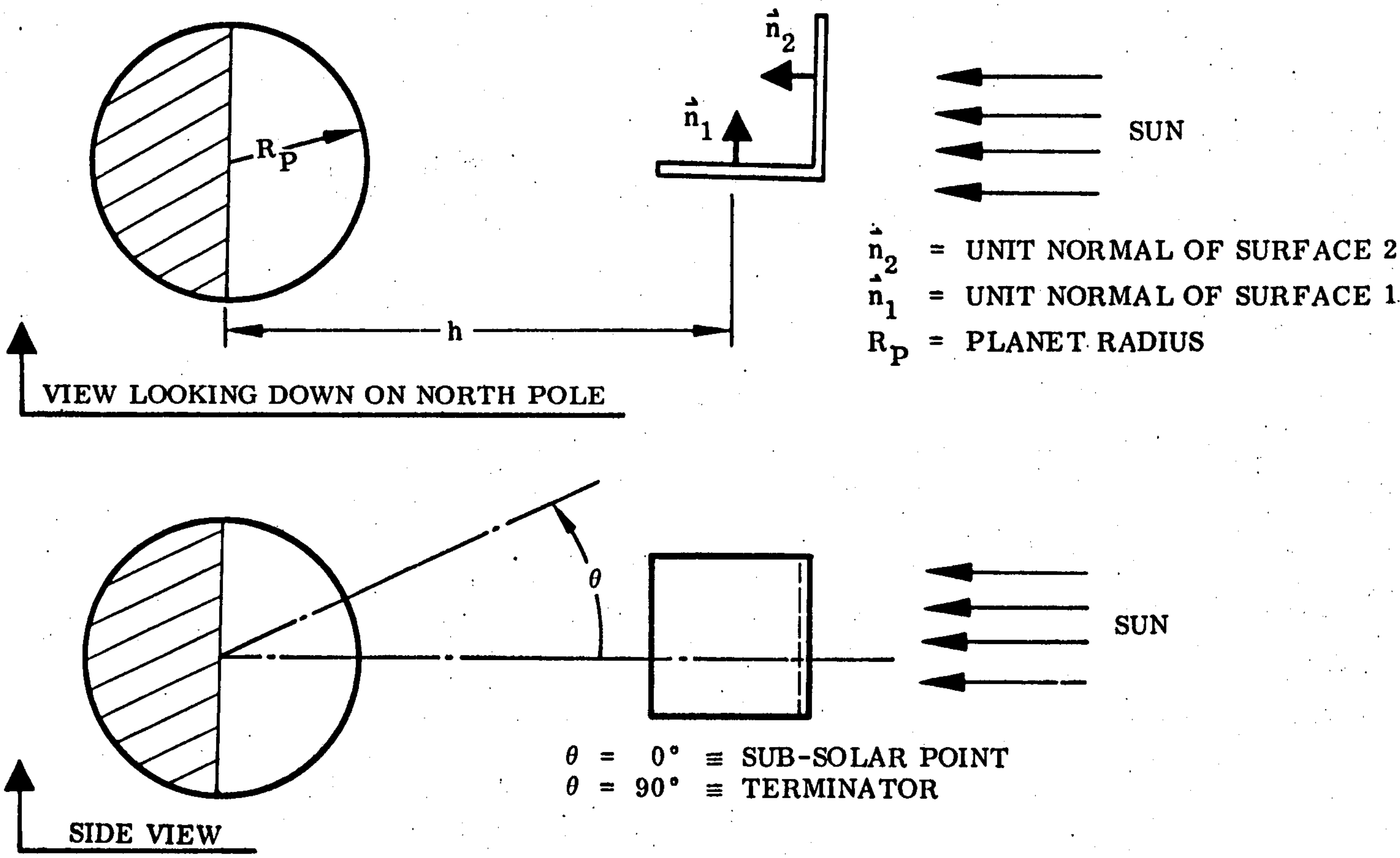
Table F-1 (Cont)

NUMERICAL RESULTS: (ALL HEAT FLUX VALUES IN BTU/(HR-FT^2))

				Absorbed Planetary Heat Flux		Absorbed Albedo Heat Flux		*Incident Planetary Heat Flux		*Incident Albedo Heat Flux	
Case	Planet	θ(°)	h(Km)	q_{1P}	q_{2P}	q_{1ST}	q_{2ST}	q_{1P}	q_{2P}	q_{1ST}	q_{2ST}
1	Venus	0	100	18.8	39.6	69.1	569.	21.2	43.2	270.	551.
2	Venus	45	100	18.6	30.3	49.0	313.				
3	Venus	90	100	15.3	16.4	0.516	0.298	17.7	17.7	2.06	0
4	Venus	180	100	9.90	0.315	0	0				
5	Venus	0	3,000	3.97	19.8	12.3	231.	4.24	21.9	45.1	234.
6	Venus	45	3,000	3.86	14.0	6.66	93.6				
7	Venus	90	3,000	3.18	3.40	0.806	0.464	3.66	3.66	3.21	0
8	Venus	0	30,000	0.0786	1.41	0.144	11.8				
9	Venus	45	30,000	0.0714	1.02	0.0676	4.09				
10	Venus	90	30,000	0.0533	0.0565	0.0231	0.0133				
11	Mars	0	100	45.1	104.	2.88	26.	50.9	114.	11.3	25.3
12	Mars	45	100	23.1	51.5	1.56	13.9				
13	Mars	90	100	9.41	10.	0.0490	0.0283	10.9	10.9	0.200	0
14	Mars	0	3,000	4.18	28.8	0.260	7.10				
15	Mars	45	3,000	2.67	13.2	0.173	3.25				
16	Mars	90	3,000	1.06	0.946	0.0409	0.0236				
17	Mars	135	3,000	—	—	Negligible	Negligible				
18	Mars	0	30,000	0.0233	1.24	0.0065	0.311				
19	Mars	45	30,000	0.0116	0.615	0.000330	0.156				
20	Mars	90	30,000	*0	*0	*0	*0				
21	Venus	0	100	9.11	1.90	110	121				
22	Venus	90	100	18.8	39.6	0.761	6.29				

*Incident fluxes do not include reflected energy.

Table F-1 (Concluded)



SCHEMATIC OF ORBIT-RADIATOR CONFIGURATION

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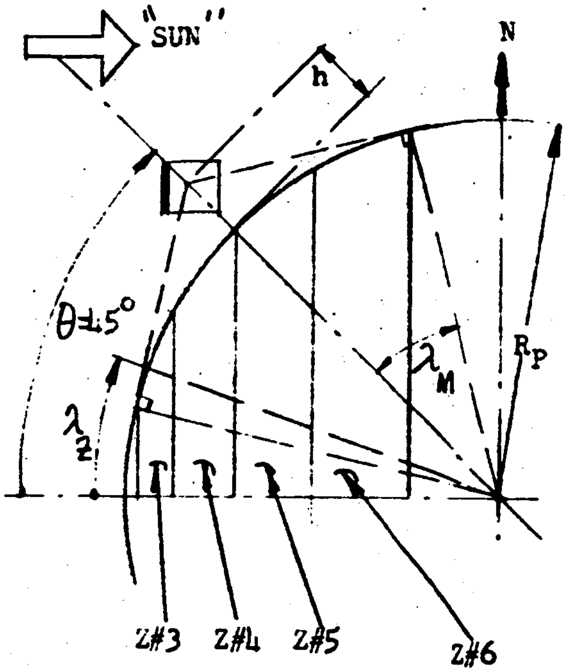
Planet Zone Breakdown



$\lambda_M = \sin^{-1}(R_P/(R_P + h)) = 14°$

Z#3: $31° < \lambda_z < 38°$

Z#4: $38° < \lambda_z < 45°$

Z#5: $45° < \lambda_z < 53°$

Z#6: $53° < \lambda_z < 59°$

Planet Configuration Factor Calculation

The calculated numerical data for zones' 3-6 are tabulated in Table F-2. Figs. F-10 and F-11 illustrate the scaled drawings obtained for Case 12 by the double projection method. Only one-half of the unshaded curves are shown. For example, the loci of the projected points j″ for surface 2 are represented by the following curves:

$\frac{1}{2}$ (Zone #3) = Curve m o b c p m

$\frac{1}{2}$ (Zone #4) = Curve m o b a n m

$\frac{1}{2}$ (Zone #5) = Curve a b . . . . g s i j . . . . n a

$\frac{1}{2}$ (Zone #6) = Curve g h t i s g

The general shading curves of Fig. F-3 are then superimposed on the non-shaded curve area bounded by the line a....h...a for each element. Shading curves due to element 1-16 are labeled as 1, 2, 3, etc., respectively. The configuration factors are then computed by measuring appropriate areas for each i. For example, consider i = 1. The configuration factors are computed from the following equations:

$$\pi (10)^2 F_{(dA_{12})(3)} = 2 A''_{mobcpm} - A''_{mnom}$$
$$\pi (10)^2 F_{(dA_{12})(4)} = 2 A''_{mobcpm} - A''_{mopm}$$
$$\pi (10)^2 F_{(dA_{12})(5)} = 2 A''_{ab....gsij...na} - A''_{mnopqrsi....m}$$
$$\pi (10)^2 F_{(dA_{12})(6)} = 2 A''_{ghtisg} - A''_{isti}$$

Note that R_s = 1 unit = 10 cm = 10000 KM = distance or length of af.

The following table shows the $F_{(dA_{im})}(Z)$ results:

	RADIATOR SURFACE 1				RADIATOR SURFACE 2			
i#	Z = 3	Z = 4	Z = 5	Z = 6	Z = 3	Z = 4	Z = 5	Z = 6
1	0.0061	0.0181	0.0178	0.245		0.0347	0.413	0.0108
2	0.0318	0.0201				0.0414	0.521	0.0121
3	0.0417	0.0201				0.0478	0.600	0.0121
4	0.0417	0.0201				0.0525	0.666	0.0121
5	0.0111	0.0188				0.0325	0.397	0.00826
6	0.0417	0.0201				0.0449	0.505	0.0108
7	0.0417					0.0512	0.601	0.0121
8	0.0417				NEGLIGIBLE	0.0535-	0.669	0.0121
9	0.0274					0.0411	0.432	0.00795
10	0.0417					0.0513	0.540	0.00987
11						0.0541	0.620	0.0121
12						0.0541	0.681	0.0121
13						0.0516	0.485	0.00733
14						0.0541	0.594	0.0105
15						0.0541	0.650	0.0121
16	0.0417	0.0201	0.0178	0.245		0.0541	0.686	0.0121
Sums	0.5768	0.3183	0.2848	0.392	0	0.7730	9.060	0.1744

The above tabular sums divided by 16 are the configuration factors $F_{(1)}(Z)$ and $F_{(2)}(Z)$ of Table F-2.

For the Mars zone breakdown, the configuration factor values F_{ZS} as determined by the double projection method are listed in Table F-3 for Case 12.

Having computed all required configuration factors, the procedure, as discussed in Appendix F.5, is followed in order to calculate the required "K" values. The "K" and heat flux results are summarized in the following table for Case 12:

Z#	σK_{1Z}*	σK_{2Z}*	σK_{1ST}*	σK_{2ST}*
3	0.1462×10^{-13}	0.465×10^{-15}	0.319×10^{-19}	0.238×10^{-18}
4	0.525×10^{-14}	0.209×10^{-13}		
5	0.118×10^{-13}	0.243×10^{-12}		
6	0.994×10^{-13}	0.783×10^{-14}		

Z#	T_Z		q_{1Z}**	q_{2Z}**	q_{1ST}**	q_{2ST}**
	°K	°R				
3	282	506	3.48	0.111		
4	275	495	1.155	4.6		
5	266	479	2.21	45.5		
6	257	462	16.3	1.28		
Totals			23.2	51.5	1.56	13.9

*Units of Btu/(sec-Ft^2-°R^4)

**Units of Btu/(Ft^2-Hr)

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F.7 REFERENCES

1. Jakob, Heat Transfer, Vol II, Wiley, 1957

2. Hamilton, D. C. and Morgan, W. R., Radiant-Interchange Configuration Factors, NACA TN 2836, 1952

3. "Proposal for Heat Flux Study", LMSC 895819, 10 August 1963

F.8 DEFINITION OF SYMBOLS

ENGLISH:

A = Surface Area

A'' = Projected surface area of visible planet surface onto base of R_s sphere containing element dA_{im}

a, b, c = Geometrical dimensions of radiator surfaces

dA_i = Elemental area of element i

dA_{im} Subscripts refer to element i of radiator surface m

$F_{(i)(j)}$ or F_{ji}, F_{ij} = "Lambertian" geometric configuration factor (Ref. 1) between surface i and j (dimensionless)

$F_{(dA_{im})(P)}$ = Same as above except replace i by dA_{im} and j by P

h = Altitude

K_{mp}, K_{mz} = Radiant interchange factor between radiator surface m and planet surface P or planet zone Z

K_{mst} = Radiant interchange factor between radiator surface m and sun

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$\vec{n}$ = Unit normal

q = Absorbed heat flux, includes shadowing and reflection effects between adjacent radiator surfaces

q_{mz}, q_{mp} = Heat flux as defined above between radiator surface m and planet zone Z or entire visible planet surface p

R_P = Planet radius

R_S = Sun radius

R_s = Radius of reference sphere

T = Temperature

GREEK:

ϕ, α, β = Angular dimensions of radiator surfaces

θ = Orbit angular position

ϵ = Infrared emissivity of radiator surface

α_s = Solar absorptivity of radiator surface

ρ = Reflectivity of radiator or planet surface

λ = Angle between planet-sun line and normal to planet surface

Φ = Angle as defined in Fig. F-7

π = 3.14 for hand calculations

σ = Stefan-Boltzmann Constant - 0.1713×10^{-8} Btu/(Hr-ft^2-$^\circ$R^4)

SUBSCRIPTS:

dA_{im} = Elemental area of element i of radiator surface m, m = 1 or 2

i, j = Denotes surface or element index number

m = Radiator surface; m = 1 (primary), m = 2 (secondary)

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P = Entire visible portion of planet surface as seen from radiator surface m

S = Sun

Z = Spherical zone of surface area $2\pi R_P^2 (1 - \cos \lambda_Z)$ as seen from radiator surface

TABLE F-2

GEOMETRIC CONFIGURATION FACTORS FROM RADIATOR SURFACE TO PLANET

PHASE I HAND CALCULATION RESULTS

*Denotes negligible F(S), i.e., less than 0.0001

**This is configuration factor from 1 to "sun-lit" portion of planet only ≅ 0

CASE #	F_{1P}	F_{2P}
1	0.388	0.790
2	0.382	0.601
3	0.322	0.322
4	0.2125	0.
5	0.0773	0.399
6	0.0770	0.281
7	0.0669	0.0669
8	0.001115	0.0286
9	0.001115	0.0207
10	0.001115	0.001115
11	0.349	0.787
13	0.298	0.298
17	**0	0.
18	*0	0.01
19	*0	0.00707
20	*0	*0
21	0.388	0.790
22	0.388	0.790

TABLE F-2 (Cont.)

	CASE 12		CASE 14		CASE 15		CASE 16	
Z #	F_{1Z}	F_{2Z}	F_{1Z}	F_{2Z}	F_{1Z}	F_{2Z}	F_{1Z}	F_{2Z}
3	0.0361	*0	0.00239	0.0454	0.00127	0.00568	*0	0.0337
4	0.0120	0.0483	0.01032	0.0894	0.00255	0.01182	0.000430	
5	0.0178	0.566	0.01222	0.0677	0.0051	0.0232	0.00182	
6	0.245	0.0109	0.00779	0.0392	0.00924	0.0339	0.00514	
7	—	—	0.00239	0.00745	0.0067	0.0378	0.00871	
8	—	—	—	—	0.00446	0.0319	—	
9	—	—	—	—	0.00159	0.0229	—	
10	—	—	—	—	*0	0.00876	—	
11	—	—	—	—	*0	0.00233	—	

TABLE F-3

CONFIGURATION FACTORS FROM PLANET TO SUN:

PHASE I HAND CALCULATION RESULTS

CASE #	F(P)(S)
1	0.0000410
2	0.0000290
3	0.00000904
4	0.
5	0.0000343
6	0.0000262
7	0.00000670
8	0.0000243
9	0.0000124
10	0.00000971
11	0.00000925
13	0.00000456
17	—
18	0.00000925
19	0.00000655
20	—
21	0.0000410
22	0.0000290

Z #	CASE 12 F(Z)(S)	CASE 14 F(Z)(S)	CASE 15 F(Z)(S)	CASE 16 F(Z)(S)
3	0.00000761	0.00000925	0.00000925	0.00000731
4	0.00000681	0.00000881	0.00000839	0.00000602
5	0.00000613	0.00000805	0.00000756	0.00000449
6	0.00000525	0.00000701	0.00000654	0.00000277
7	—	0.00000566	0.00000530	0.000000934
8	—	—	0.00000392	—
9	—	—	0.00000249	—
10	—	—	0.000000806	—
11	—	—	0.	—

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TABLE F-4

PLANETARY DATA

	VENUS	MARS
R_P ≡ Planet radius, km	6200	3335
$T_{D.S.}$ ≡ Planet dark side surface temperature, °K	235	200
$T_{S.S.}$ ≡ Planet sub-solar surface temperature, °K	235	300
Planet albedo ≡ ρ	0.73	0.15
R_{P_S} ≡ Planet-sun distance, km	108×10^6	228×10^6
T_S ≡ Solar temperature, °K	6000 (or 10800°R)	
R_S ≡ Sun radius, km	6.93×10^5 (or 4.3×10^5 s.m.	

TABLE F-5

LIST OF PLANET ZONE BREAKDOWN
FOR
MARS NOON ORBIT STUDIES

Each zone is bounded in the range: $\lambda_Z < \lambda < \lambda_{Z+1}$

CASE 12				CASE 14		
Z #	λ_Z (°)	λ_{Z+1} (°)	A, 10^{13} Ft^2	λ_Z (°)	λ_{Z+1} (°)	A, 10^{13} Ft^2
3	31	38	1.56	0	11.6	0.45
4	38	45	1.83	11.6	23.2	1.372
5	45	53	2.05	23.2	34.8	2.18
6	53	59	2.28	34.8	46.4	2.97
7	—	—	—	46.4	58.0	3.60

CASE 15				CASE 16		
Z #	λ_Z (°)	λ_{Z+1} (°)	A, 10^{13} Ft^2	λ_Z (°)	λ_{Z+1} (°)	A, 10^{13} Ft^2
3	0	20	1.35	0	32	2.79
4	20	30	1.664	32	43.6	3.45
5	30	40	2.25	43.6	55.2	3.99
6	40	50	2.77	55.2	66.8	4.35
7	50	60	3.22	66.8	78.4	4.53
8	60	70	3.56			
9	70	80	3.78			
10	80	90	3.91			
11	90	102.5	4.86			

Appendix G

PARAMETRIC STUDY RESULTS FOR VENUS

G.1 PLANET VENUS, CONFIGURATION 1A, SUN ORIENTED (Figs. G-1 and G-2)

G.1.1 NOON orbit

Position 1 (192 pgs)

- 8 orbit positions
- 8 altitudes/orbit position
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

Position 2 (192 pgs)

Same as Position 1; para. G.1.1

G.1.2 45 Degree orbit

Position 1 (192 pgs)

Same as Position 1; para. G.1.1

Position 2 (192 pgs)

Same as Position 1; para. G.1.1

Position 3 (192 pgs)

Same as Position 1; para. G.1.1

G.1.3 TWILIGHT orbit

Position 1 (192 pgs)

Same as Position 1; para. G.1.1

G.1.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

<u>Vary (α_s/ϵ) ratios</u> (48 pgs)

- 4 (α_s/ϵ) ratios, surface 1
- 4 (α_s/ϵ) ratios, surface 2/(α_s/ϵ) ratio, surface 1
- 3 (a/b) ratios/(α_s/ϵ) ratio, surface 2
- 3 (c/b) ratios/(a/b) ratio

<u>With α = 120°(Surface 2 a trapezoid)</u> (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1203 pgs)

G.2 PLANET VENUS, CONFIGURATION 1B, SUN ORIENTED (Figs. G-3 and G-4)

G.2.1 NOON orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. G.1.1

G.2.2 45 Degree orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 3</u> (192 pgs)

Same as Position 1; para. G.1.1

G.2.3 TWILIGHT orbit

Position 1 (192 pgs)

Same as Position 1; para. G.1.1

G.2.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

Vary c/b ratios separately (9 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios, surface 2/(a/b) ratio
- 3 (c/b) ratios, surface 3/(c/b) ratio, surface 2

Vary (α_s/ϵ) ratios (48 pgs)

- 4 (α_s/ϵ) ratios, surface 1
- 4 (α_s/ϵ) ratios, surfaces 2&3/(α_s/ϵ) ratio, surface 1
- 3 (a/b) ratios/(α_s/ϵ) ratio, surfaces 2&3
- 3 (c/b) ratios/(a/b) ratio

With α = 120° (Surfaces 2and 3 trapezoids) (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1212 pgs)

G.3 PLANET VENUS, CONFIGURATION 1B, PLANET ORIENTED (Figs. G-5 and G-6)

G.3.1 NOON orbit

Position 3 (192 pgs)

Same as Position 1; para. G.1.1

Position 2 (192 pgs)

Same as Position 1; para. G.1.1

G.3.2 45 Degree orbit

<u>Position 3</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 1</u> (192 pgs)

G.3.3 TWILIGHT orbit, orbit position 4

<u>Position 1</u> (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

<u>Position 3</u> (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

(1008 pgs)

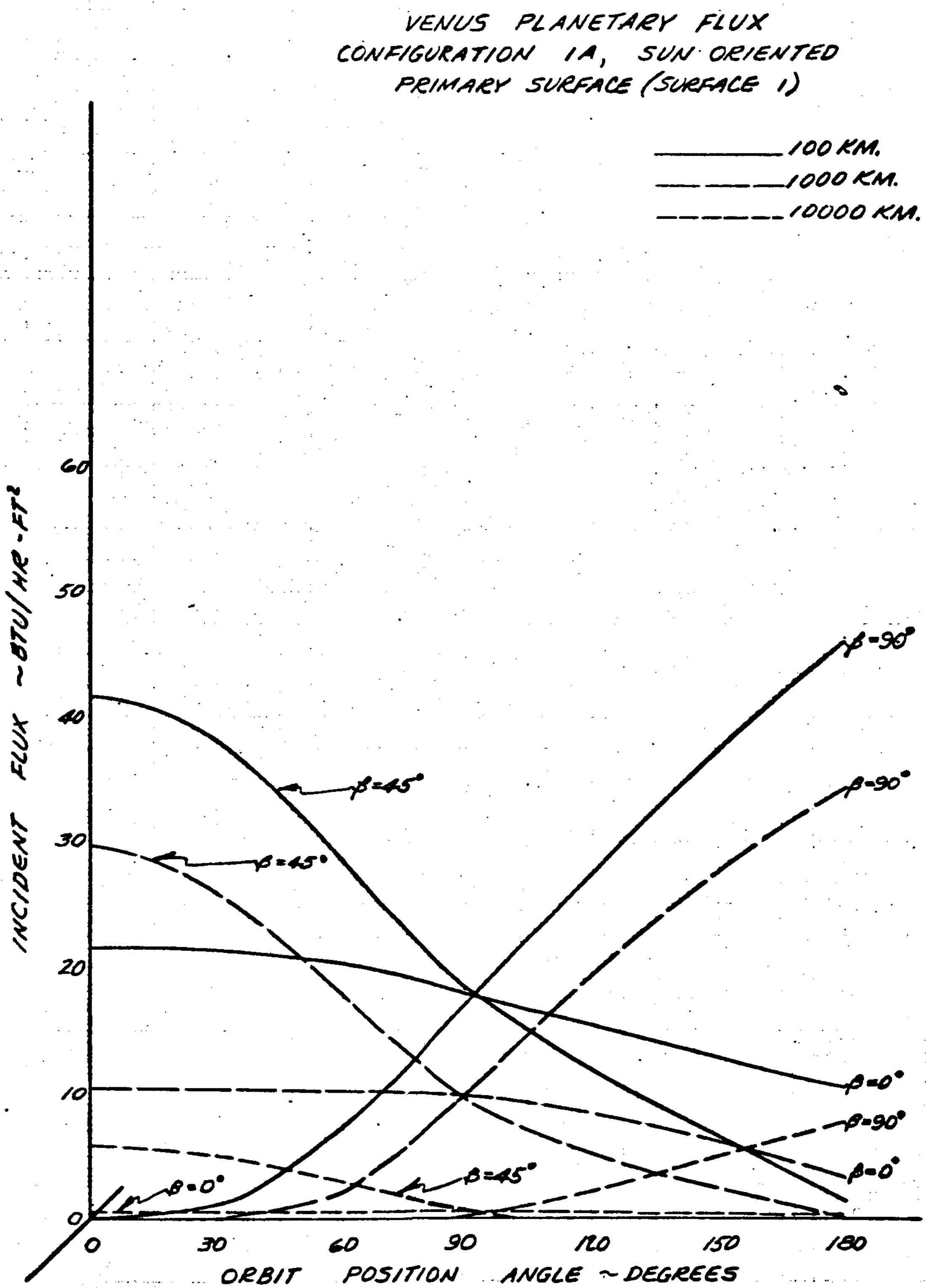

Fig. G-1 Venus Planetary Flux Configuration 1A Sun Oriented

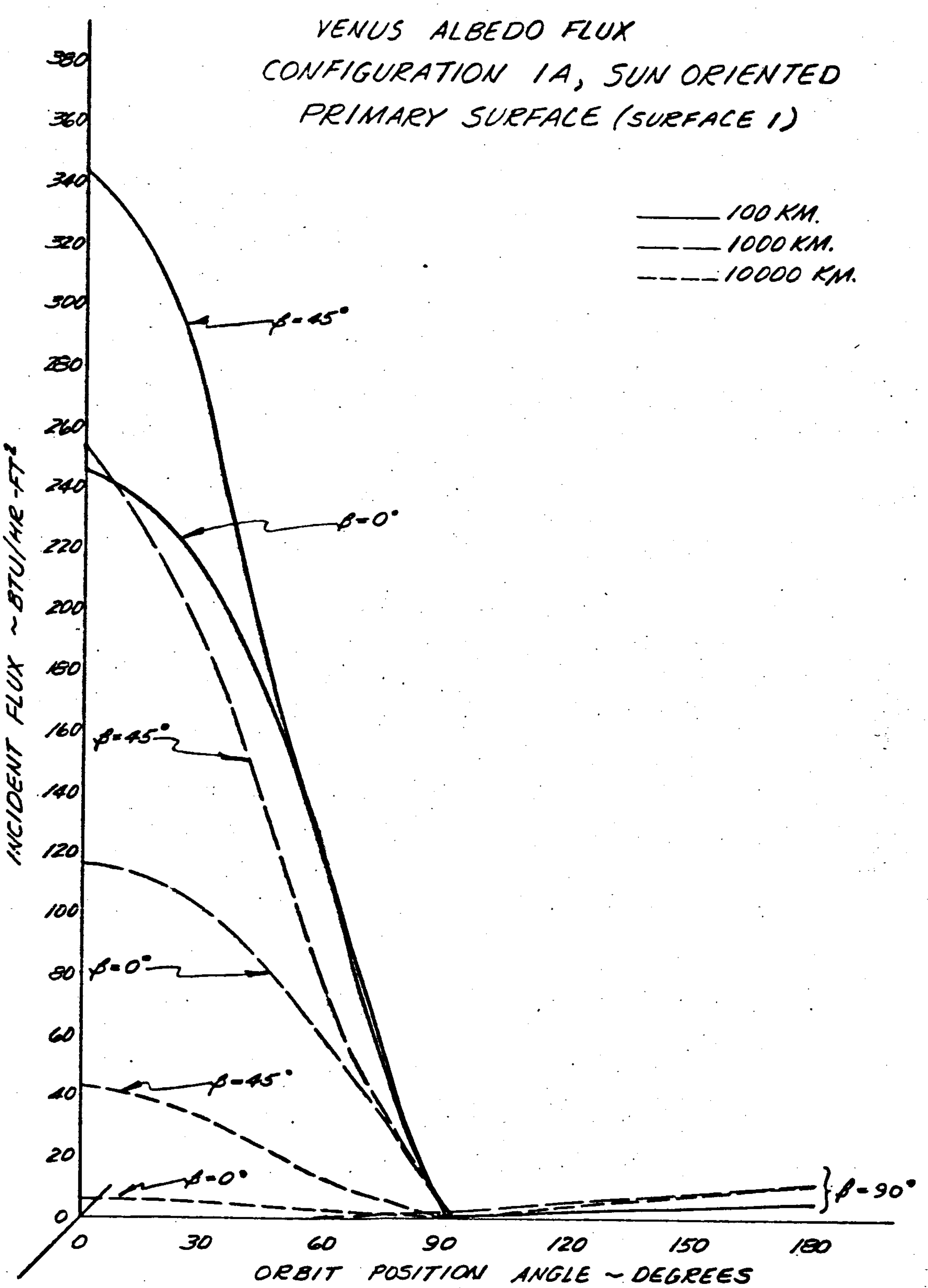

Fig. G-2 Venus Albedo Flux Configuration 1A
Sun Oriented

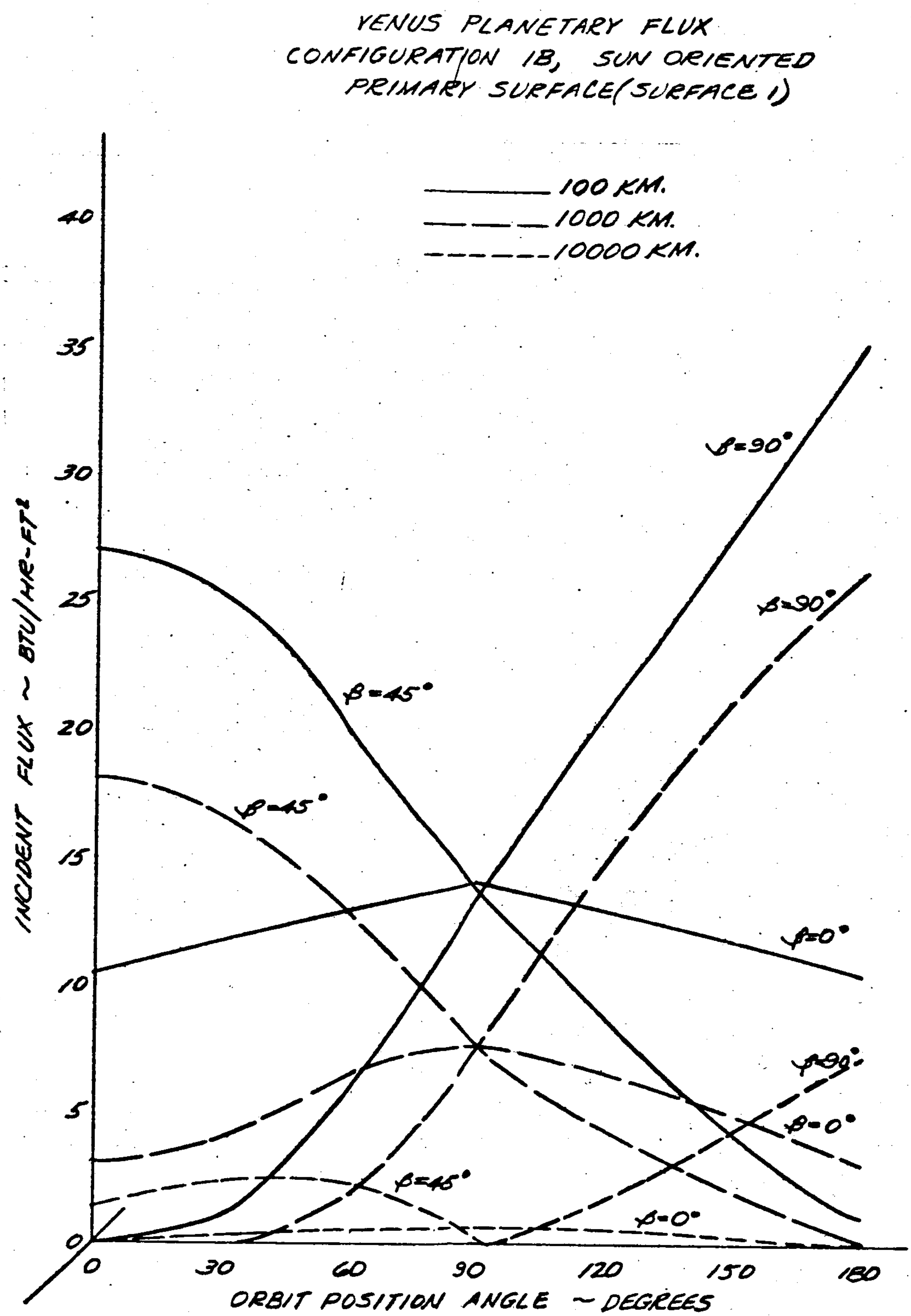

Fig. G-3 Venus Planetary Flux Configuration 1B
Sun Oriented

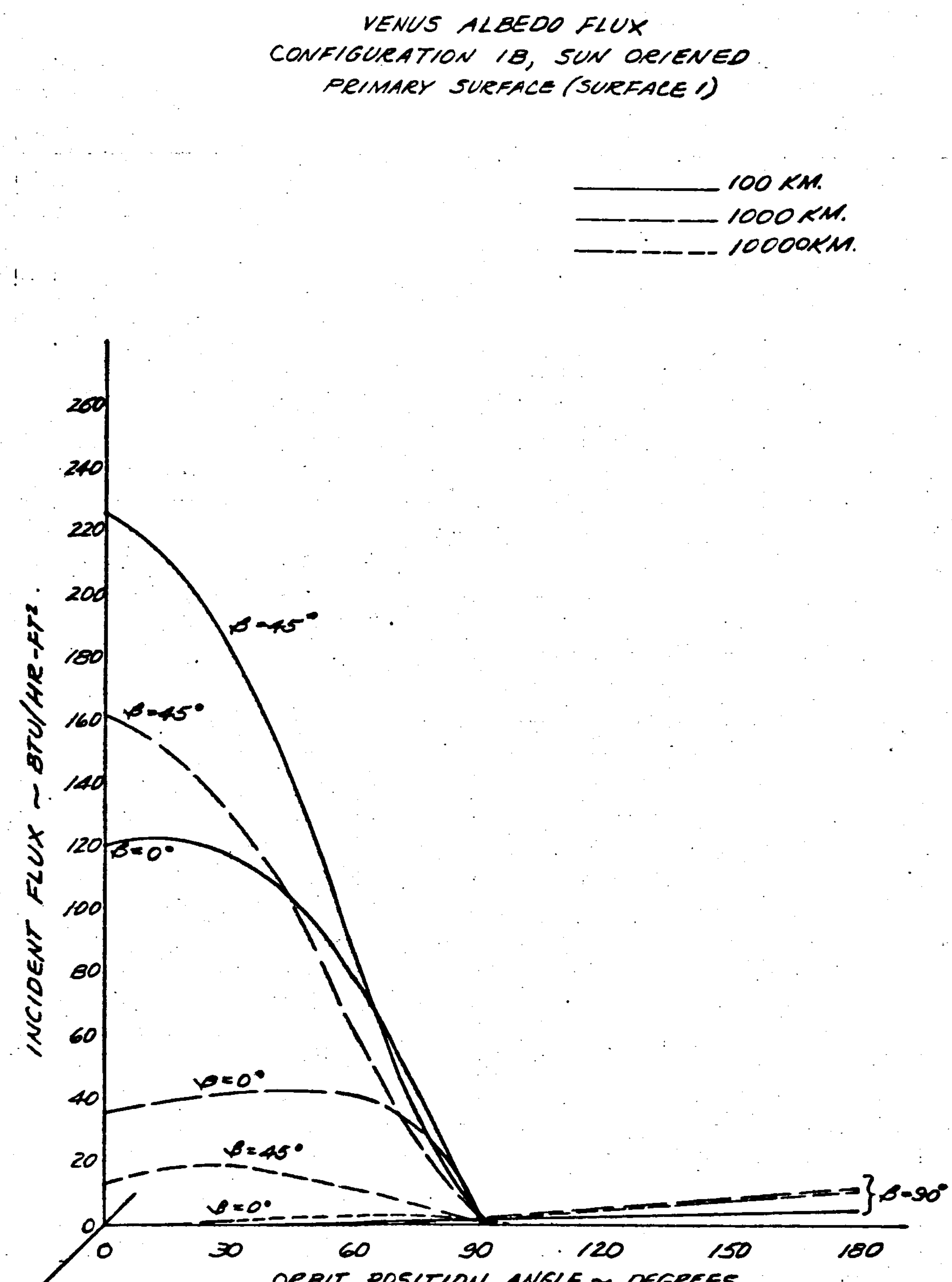

Fig. G-4 Venus Albedo Flux Configuration 1B
Sun Oriented

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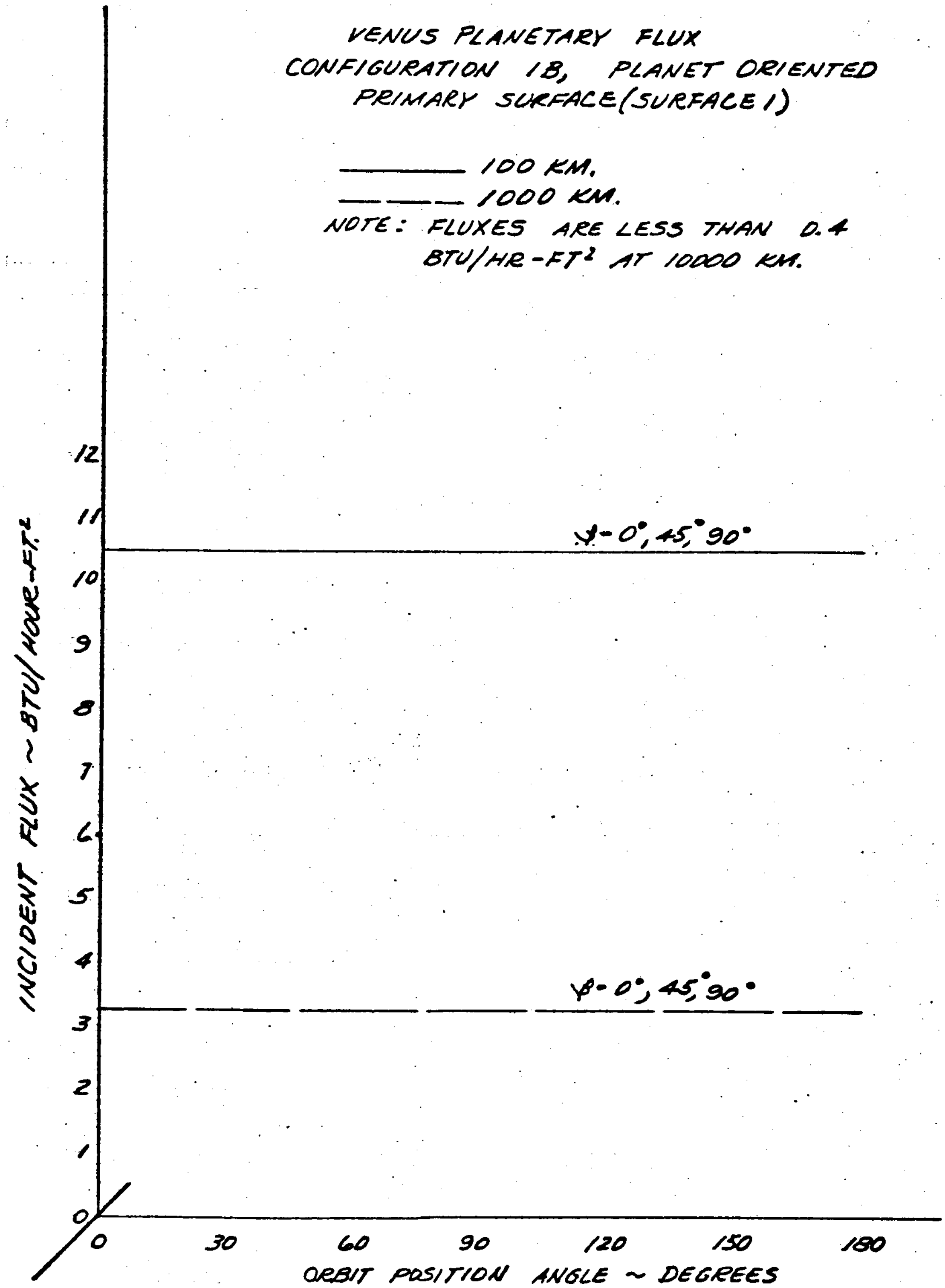

Fig. G-5 Venus Planetary Flux Configuration 1B
Planet Oriented

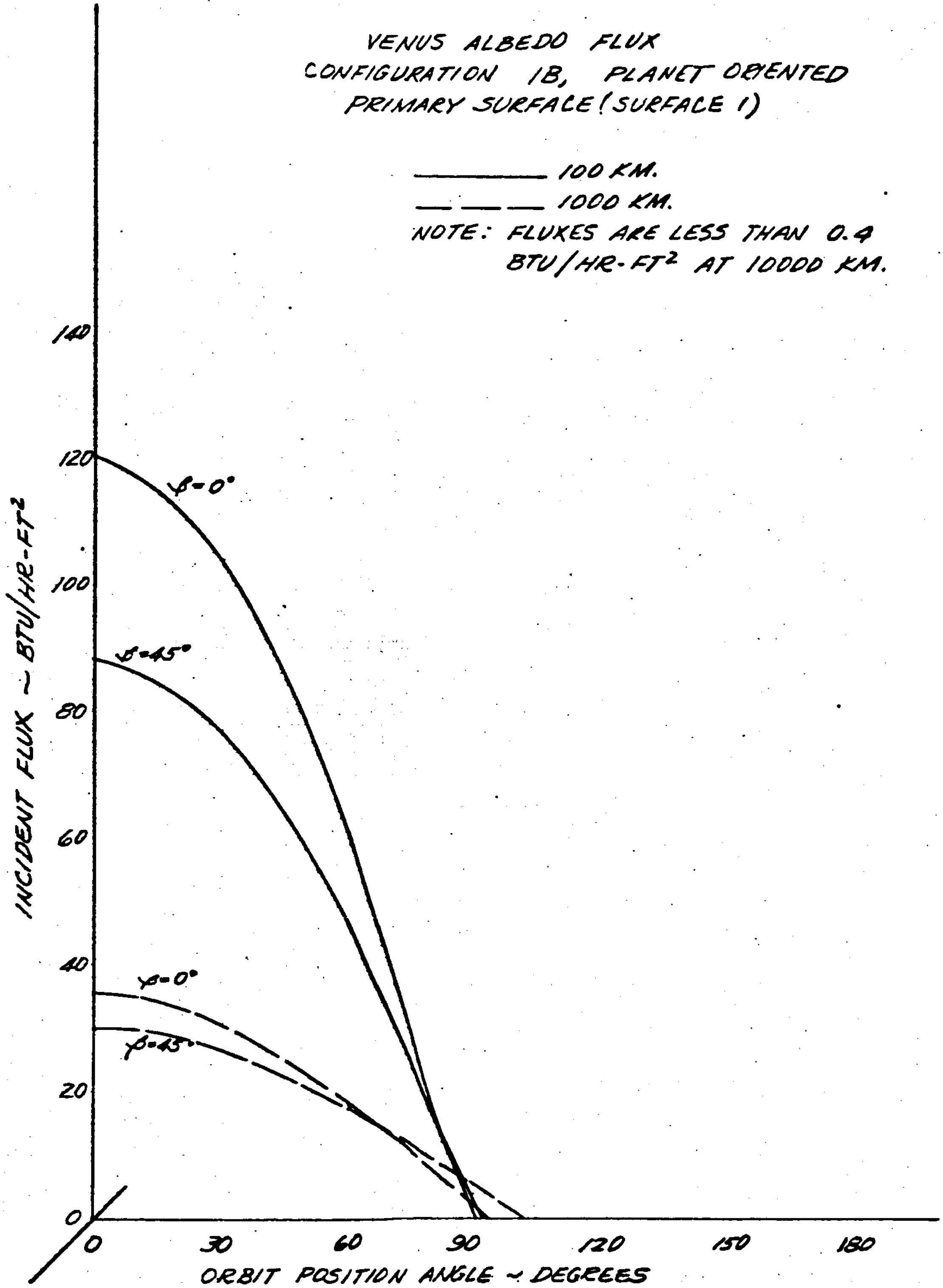

Fig. G-6 Venus Albedo Flux Configuration 1B
Planet Oriented

Appendix H

PARAMETRIC STUDY RESULTS FOR MARS

H.1 PLANET MARS, CONFIGURATION 1A, SUN ORIENTED (Figs. H-1 and H-2)

H.1.1 NOON orbit

<u>Position 1</u> (192 pgs)

- 8 orbit positions
- 8 altitudes/orbit position
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

H.1.2 45 Degree orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 3</u> (192 pgs)

Same as Position 1; para. H.1.1

H.1.3 TWILIGHT orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

H.1.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

<u>Vary (α_s/ε) ratios</u> (48 pgs)

- 4 (α_s/ε) ratios, surface 1
- 4 (α_s/ε) ratios, surface 2/(α_s/ε) ratio, surface 1
- 3 (a/b) ratios/(α_s/ε) ratio, surface 2
- 3 (c/b) ratios/(a/b) ratio

<u>With α = 120° (surface 2 a trapezoid)</u> (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1203 pgs)

H.2 PLANET MARS, CONFIGURATION 1B, SUN ORIENTED (Figs. H-3 and H-4)

H.2.1 NOON orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

H.2.2 45 Degree orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 3</u> (192 pgs)

Same as Position 1; para. H.1.1

H-2

H.2.3 TWILIGHT orbit

Position 1 (192 pgs)

Same as Position 1; para. H.1.1

H.2.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

Vary c/b ratios separately (9 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios, surface 2/(a/b) ratio
- 3 (c/b) ratios, surface 3/(c/b) ratio, surface 2

Vary (α_s/ϵ ratios) (48 pgs)

- 4 (α_s/ϵ) ratios, surface 1
- 4 (α_s/ϵ) ratios, surfaces 2&3/(α_s/ϵ) ratio, surface 1
- 3 (a/b) ratios/(α_s/ϵ) ratio, surfaces 2&3
- 3 (c/b) ratios/(a/b) ratio

With α = 120° (Surfaces 2 and 3 trapezoids) (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1212 pgs)

H.3 PLANET MARS, CONFIGURATION 1B, PLANET ORIENTED (Figs. H-5 and H-6)

H.3.1 NOON orbit

Position 3 (192 pgs)

Same as Position 1; para. H.1.1

Position 2 (192 pgs)

Same as Position 1; para. H.1.1

H.3.2 45 Degree orbit

<u>Position 3</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

H.3.3 TWILIGHT orbit, orbit position 4

<u>Position 1</u> (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

<u>Position 3</u> (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

(1008 pgs)

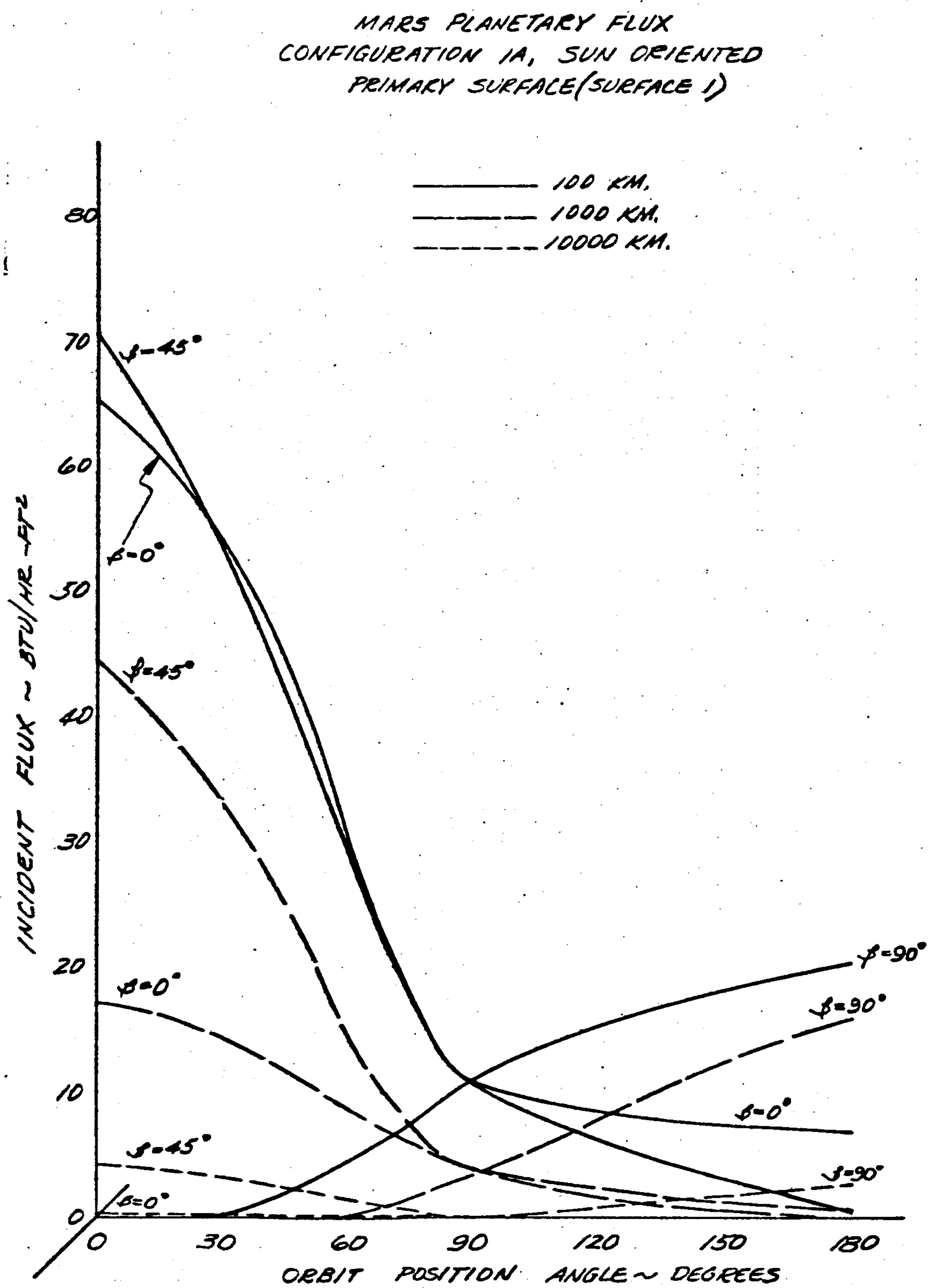

Fig. H-1 Mars Planetary Flux Configuration 1A
Sun Oriented

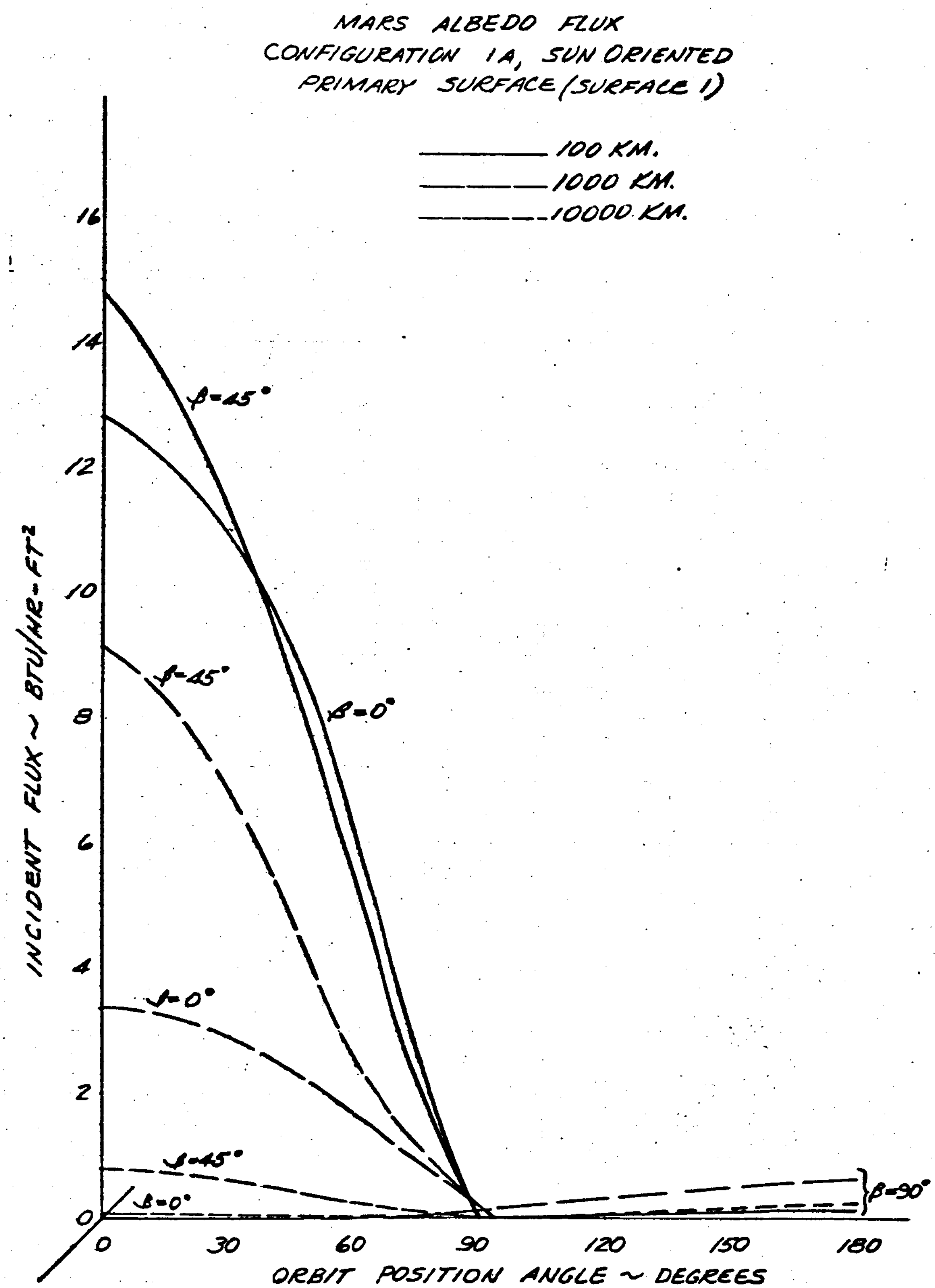

Fig. H-2 Mars Albedo Flux Configuration 1A
Sun Oriented

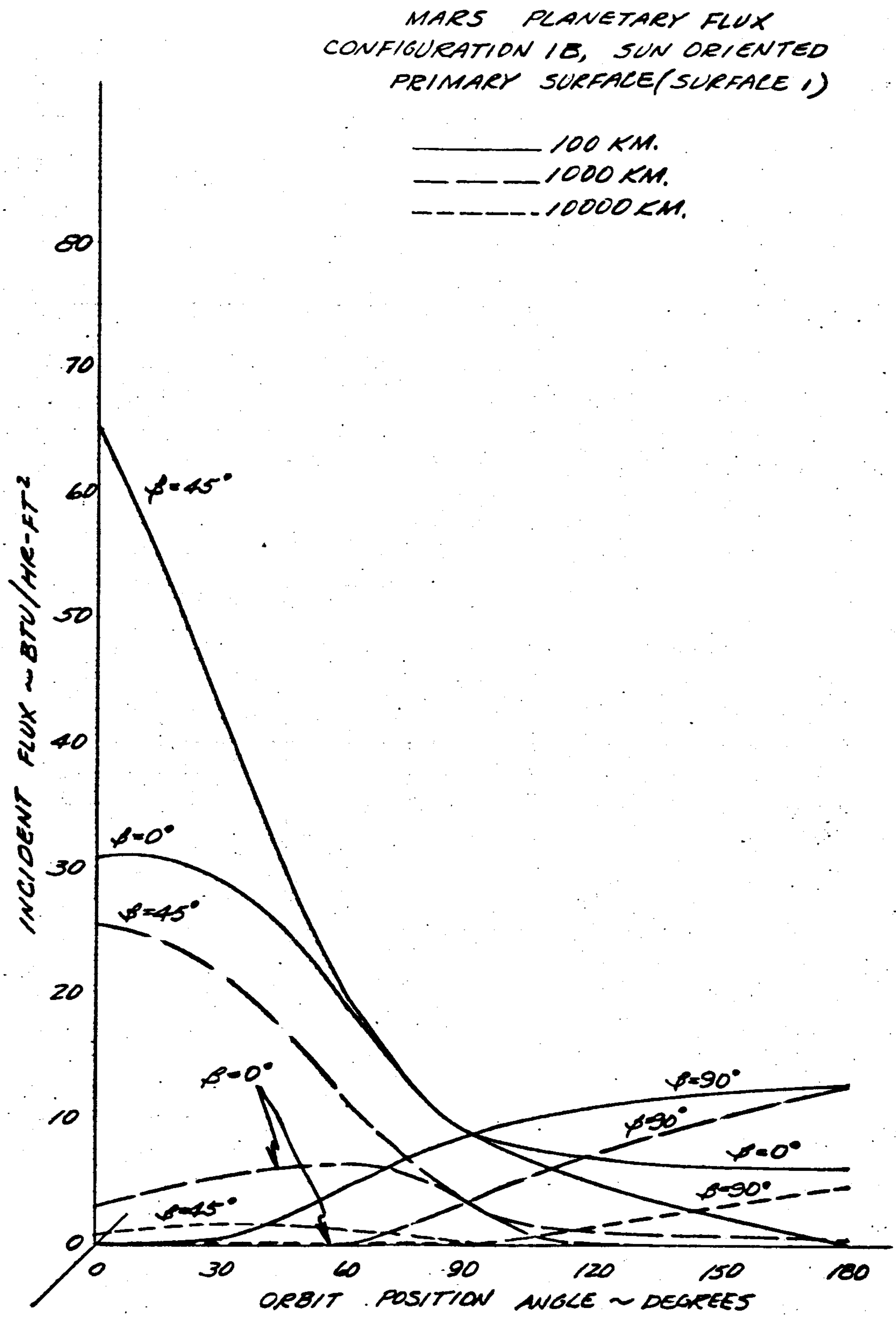

Fig. H-3 Mars Planetary Flux Configuration 1B
Sun Oriented

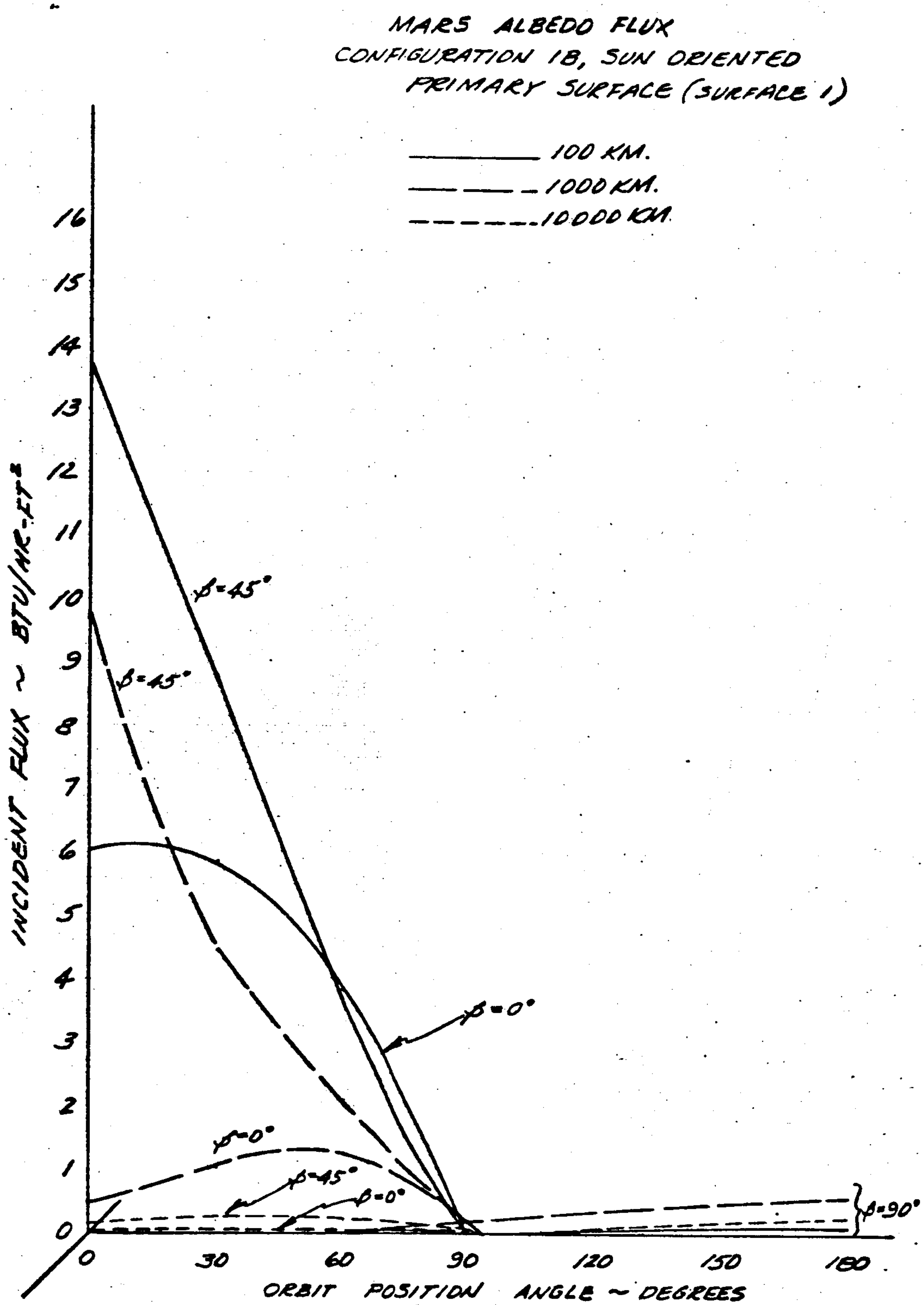

Fig. H-4 Mars Albedo Flux Configuration 1B
Sun Oriented

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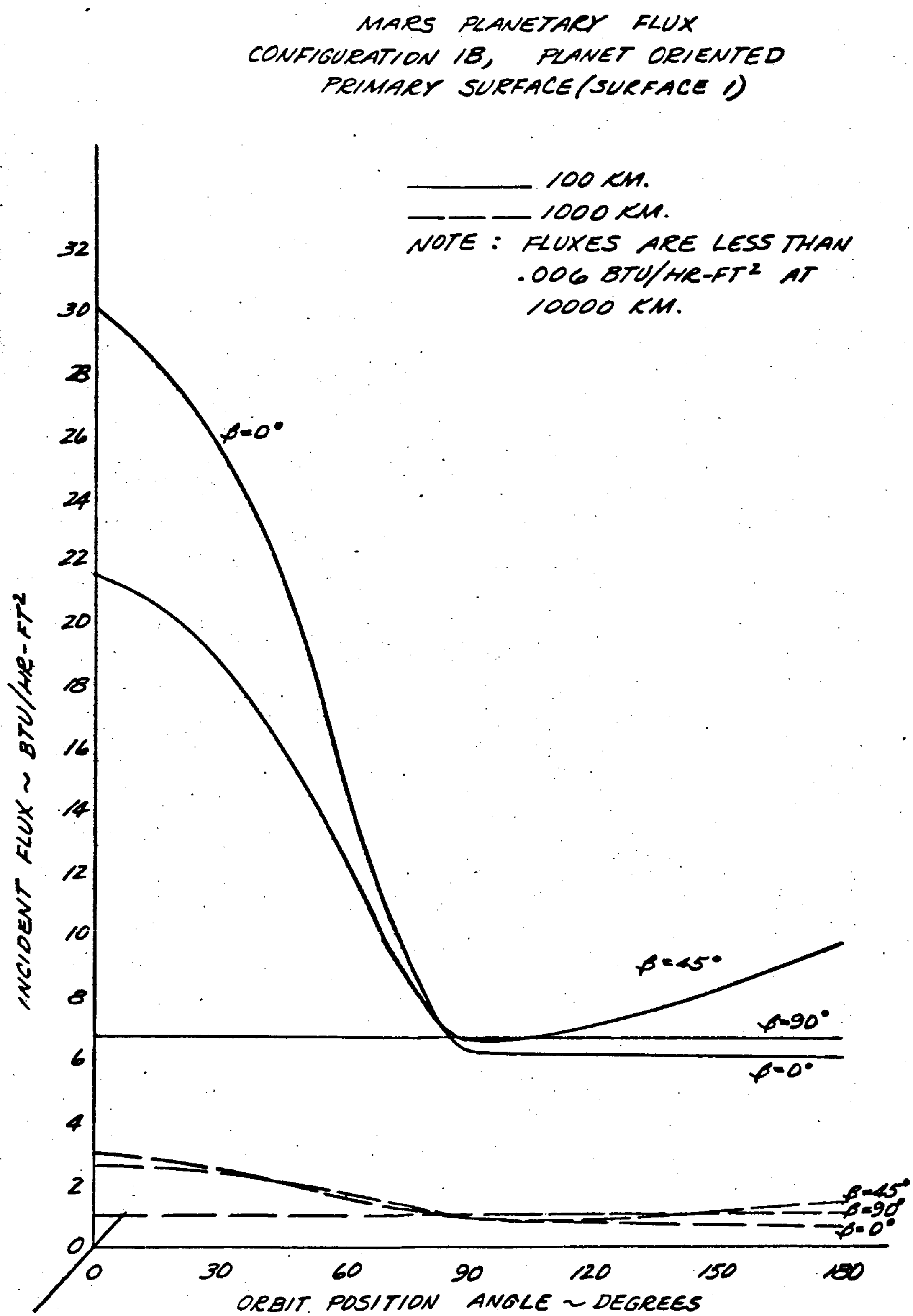

Fig. H-5 Mars Planetary Flux Configuration 1B
Planet Oriented

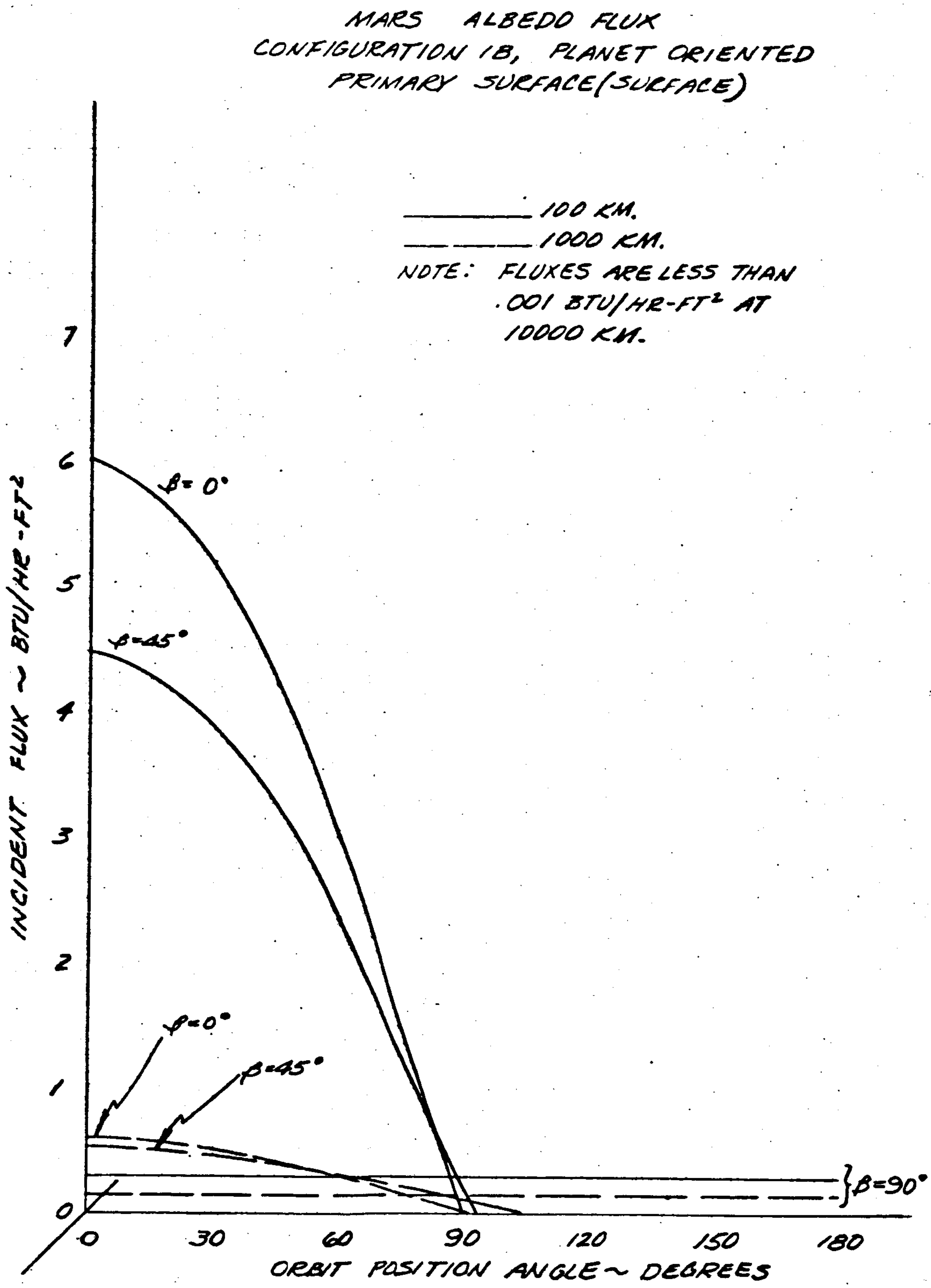

Fig. H-6 Mars Albedo Flux Configuration 1B Planet Oriented

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Appendixes G and H
PRESENTATION OF RESULTS

The parametric study results are listed three points per page. The data for each point are grouped in five blocks: HEAT FLUX block, VIEW FACTORS block, RAD. CONSTS.-SOLAR + REFLECTED block, RAD. CONSTS.-PLANETARY block, and POINT IDENTIFICATION block:

HEAT FLUX block: The heat fluxes to each surface are listed across the top of each point. The left-hand column is the surface identification number. The fluxes to each surface are listed from left to right in the following order:

1. QS(I) = direct incident solar flux
2. QS(A) = total absorbed solar flux
3. QR(I) = direct incident albedo flux
4. QR(A) = total absorbed albedo flux
5. QP(I) = direct incident planetary flux
6. QP(A) = total absorbed planetary flux

NOTE: The values of the fluxes, view factors, and radiation constants are listed in "floating point" form. Each number consists of a fraction and an exponent with a power of ten by which the fraction is multiplied. For example, the number 0.13918E 02 represents $0.13918 \times 10^{+02}$ or 13.918. Similarly, the number 0.78650E-01 is 0.78650×10^{-01} or 0.078650.

VIEW FACTORS block: The view factors between sun, planet, and two (or three) surfaces are listed in an array just below the heat fluxes. The symbols at the top of each column, and the left of each row identify the surface: S = sun, P = planet, 1 = surface 1, 2 = surface 2, 3 = surface 3. The number at the intersection of a row and column is the view factor from the surface at the left of the row to the surface at the top of the column.

RAD. CONSTS. - SOLAR + REFLECTED block: The radiation constants ($\mathcal{F}$A) for solar and albedo radiation are listed at the bottom left of each point. The arrangement in columns and rows is the same as the view factor arrangement (the column identification symbols have been omitted to conserve space). The S row (or column) contains the radiation constants for solar radiation, and is used in computing the net direct radiant interchange between the sun and the surfaces assuming no reflection from the planet. The P row (or column) contains the radiation constants for albedo radiation, and is used in computing the net radiant interchange between the sun and the surfaces through reflection from the planet. The S-S, S-P, and P-P quantities represent the flux reflected by the surfaces back onto the sun or planet. They may generally be ignored. The area in the $\mathcal{F}$A expressions is based on a "b" dimension on surface 1 of 4 ft.

RAD. CONSTS. - PLANETARY block: The radiation constants ($\mathcal{F}$A) for planetary radiation are listed at the bottom right of each point. The arrangement in columns and rows is the same as the view factor arrangement (the column identification symbols have been omitted to conserve space). The S row and column are blank because there is no planetary radiation from the sun. The P row (or column) contains the radiation constants for planetary radiation, and is used in computing the net radiant interchange between the planet and the surfaces. The P-P quantity represents the planetary flux reflected by the surfaces back onto the planet. The area in the $\mathcal{F}$A expressions is based on a "b" dimension on surface 1 of 4 ft.

<u>POINT IDENTIFICATION block</u>: The upper right-hand corner of each point contains the identification of the point. Each point is identified as follows:

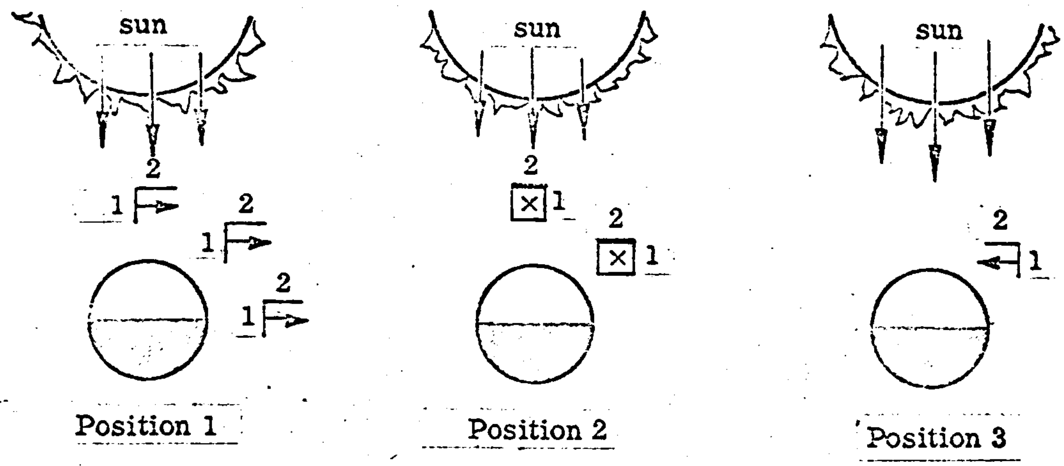
- PLANET - VENUS or MARS. Identifies the planet for which the data are computed.
- ALTITUDE - 100 km, 300 km, 500 km, 1000 km, 3000 km, 5000 km, 10,000 km or 30,000 km. Indicates the altitude of the satellite above the mean planet surface.
- ORBIT - NOON POLAR, 45 D POLAR, or TWI. POLAR. Indicates the satellite orbit. The NOON POLAR orbit crosses directly over the planet subsolar point. The 45 D POLAR orbit crosses the illuminated side of the planet midway between the subsolar point and the terminator. The TWI. POLAR orbit is directly over the terminator.

- ORIENTATION - SUN or PLANET. SUN indicates that surface 1 is oriented parallel to the rays of the sun, with surface 2 normal to the rays on the side toward the sun. PLANET indicates that surface 1 is perpendicular to the planet's surface, with surface 2 parallel to the planet's surface on the side away from the planet.

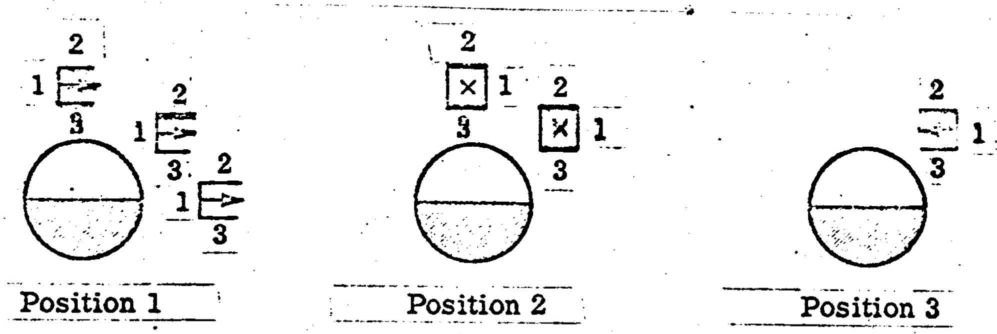
- CONFIGURATION - 1A or 1B. Configuration 1A consists of two surfaces with surface 2 extending at a right angle from one edge of surface 1. Configuration 1B consists of three surfaces with surface 2 extending at a right angle from one edge of surface 1, and surface 3 extending at a right angle from the opposite edge.

- POSITION - 1, 2, or 3. Indicates the direction surface 1 faces. With the satellite traveling north-to-south over the illuminated side of the planet, POSITION 1 indicates that surface 1 is facing west, POSITION 2 indicates that surface 1 is facing south in the SUN orientation or north in the PLANET orientation, and POSITION 3 indicates that surface 1 is facing east. (See Fig. G/H-1)

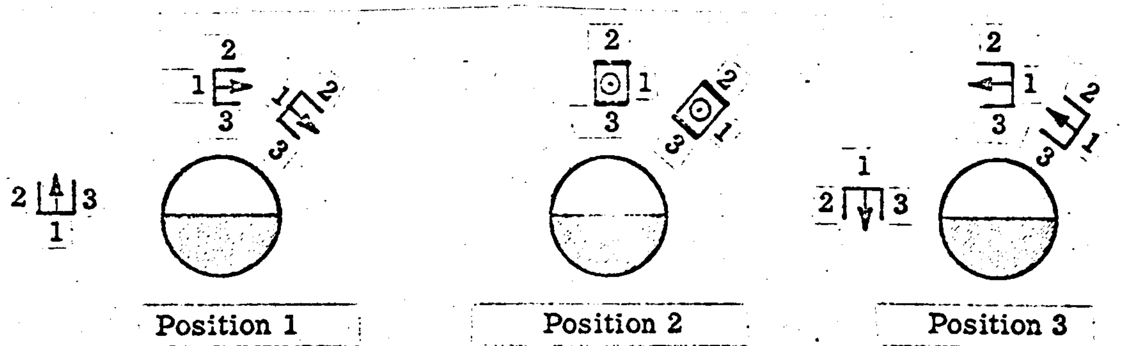
- ORBIT POSITION - Positions 1 through 8. Indicates the orbital location of the satellite. Position 1 is directly over the north pole of the planet; Position 2 is 60° north of the



(a) Configuration 1a, sun-oriented



(b) Configuration 1b, sun-oriented



(c) Configuration 1b, planet-oriented

LEGEND: → Unit normal to surface 1 in plane of paper
× Unit normal to surface 1 into paper
⊙ Unit normal to surface 1 out of paper

NOTE: View is looking down on north pole at planet. Surfaces are shown at orbit Position 4

Fig. G/H-1 Position and Orientation

equator on the illuminated side of the planet; Position 3 is 30° north; Position 4 is over the equator; Position 5 is 30° south; Position 6 is 60° south; Position 7 is over the South Pole; and Position 8 is over the equator on the dark side of the planet. Note that the sun is assumed to be located over the equator so that the planet's north and south poles are located on the terminator.

- SURFACE 1 2 3 - The remainder of the identification block identifies the dimensions and radiation properties of the surfaces. The data is displayed in three columns: column 1 referring to surface 1, column 2 to surface 2, and column 3 to surface 3. (Configuration 1A consists of only two surfaces, so column 3 is filled with zeros.)

- A/B, C/B - Specifies the dimension ratios of the three surfaces: a/b for surface 1 in column 1, c/b for surface 2 in column 2, and c/b for surface 3 in column 3. (See Fig. G/H-2)

ABSORP. - The solar absorptivity of the three surfaces.

EMISS. - The infrared emissivity of the three surfaces.

ALPHA - The trapezoid angle (see Fig. G/H-2) of surfaces 2 and 3.

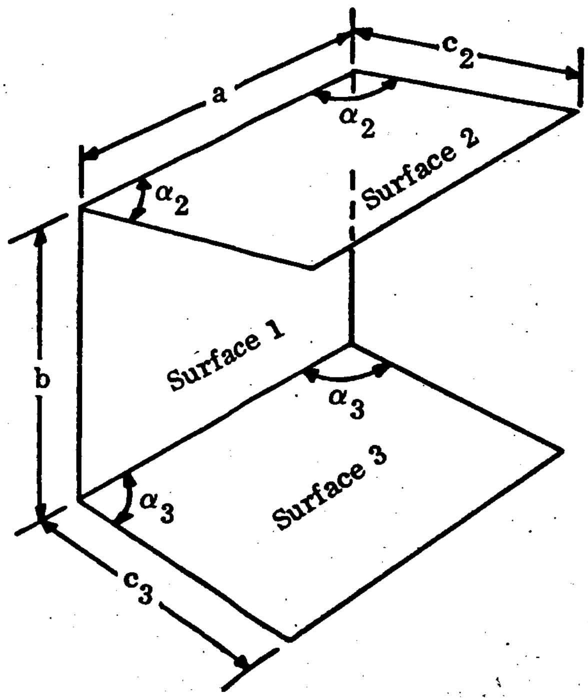


Fig. G/H-2 Surface Dimensions

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JPL ~~subcontract~~ 950674

Heat Flux Study

15 July 1956

LMSC M-16-64-1 (A)

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Appendix G
PARAMETRIC STUDY RESULTS FOR VENUS

G.1 PLANET VENUS, CONFIGURATION 1A, SUN ORIENTED (Figs. G-1 and G-2)

G.1.1 NOON orbit

Position 1 (192 pgs)

- 8 orbit positions
- 8 altitudes/orbit position
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

Position 2 (192 pgs)

Same as Position 1; para. G.1.1

G.1.2 45 Degree orbit

Position 1 (192 pgs)

Same as Position 1; para. G.1.1

Position 2 (192 pgs)

Same as Position 1; para. G.1.1

Position 3 (192 pgs)

Same as Position 1; para. G.1.1

G.1.3 TWILIGHT orbit

Position 1 (192 pgs)

Same as Position 1; para. G.1.1

G.1.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

<u>Vary (α_s/ϵ) ratios</u> (48 pgs)

- 4 (α_s/ϵ) ratios, surface 1
- 4 (α_s/ϵ) ratios, surface 2/(α_s/ϵ) ratio, surface 1
- 3 (a/b) ratios/(α_s/ϵ) ratio, surface 2
- 3 (c/b) ratios/(a/b) ratio

<u>With α = 120°(Surface 2 a trapezoid)</u> (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1203 pgs)

G.2 PLANET VENUS, CONFIGURATION 1B, SUN ORIENTED (Figs. G-3 and G-4)

G.2.1 NOON orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. G.1.1

G.2.2 45 Degree orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. G.1.1

<u>Position 3</u> (192 pgs)

Same as Position 1; para. G.1.1

G.2.3 TWILIGHT orbit

Position 1 (192 pgs)

Same as Position 1; para. G.1.1

G.2.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

Vary c/b ratios separately (9 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios, surface 2/(a/b) ratio
- 3 (c/b) ratios, surface 3/(c/b) ratio, surface 2

Vary (α_s/ϵ) ratios (48 pgs)

- 4 (α_s/ϵ) ratios, surface 1
- 4 (α_s/ϵ) ratios, surfaces 2&3/(α_s/ϵ) ratio, surface 1
- 3 (a/b) ratios/(α_s/ϵ) ratio, surfaces 2&3
- 3 (c/b) ratios/(a/b) ratio

With $\alpha = 120^\circ$ (Surfaces 2and 3 trapezoids) (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1212 pgs)

G.3 PLANET VENUS, CONFIGURATION 1B, PLANET ORIENTED (Figs. G-5 and G-6)

G.3.1 NOON orbit

Position 3 (192 pgs)

Same as Position 1; para. G.1.1

Position 2 (192 pgs)

Same as Position 1; para. G.1.1

G.3.2 45 Degree orbit

Position 3 (192 pgs)

Same as Position 1; para. G.1.1

Position 2 (192 pgs)

Same as Position 1; para. G.1.1

Position 1 (192 pgs)

G.3.3 TWILIGHT orbit, orbit position 4

Position 1 (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

Position 3 (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

(1008 pgs)

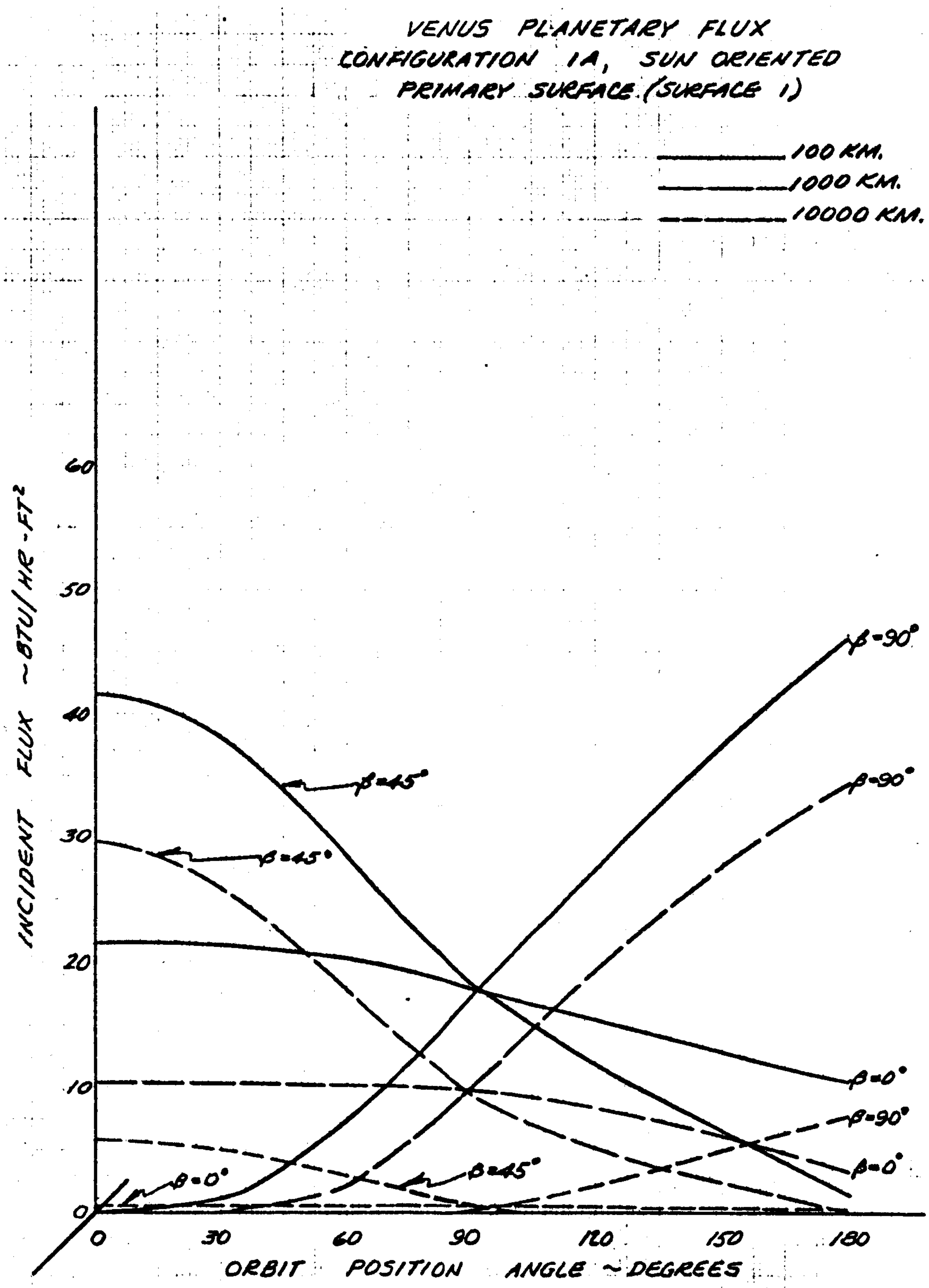


Fig. G-1 Venus Planetary Flux Configuration 1A
Sun Oriented

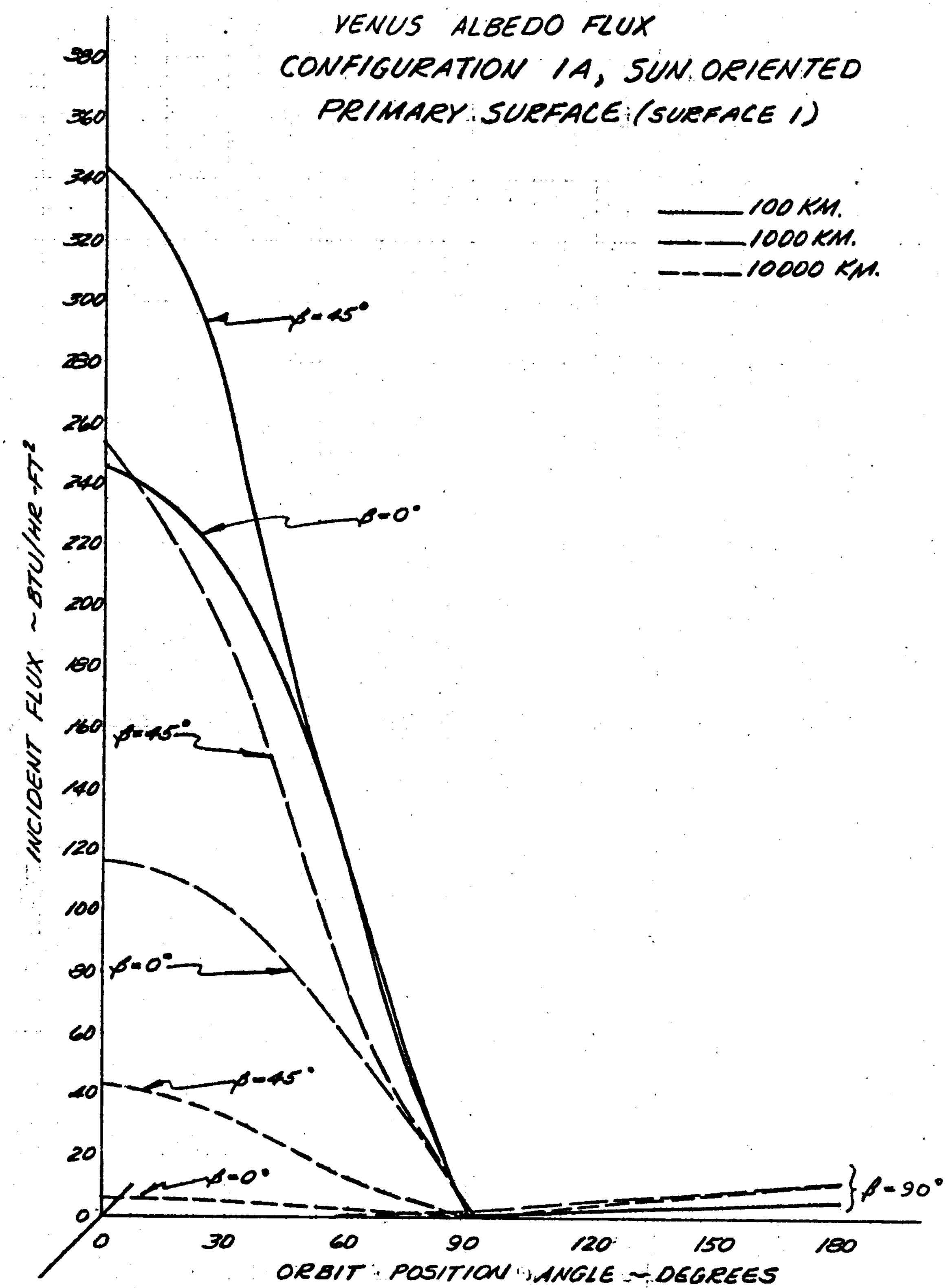


Fig. G-2 Venus Albedo Flux Configuration 1A
Sun Oriented

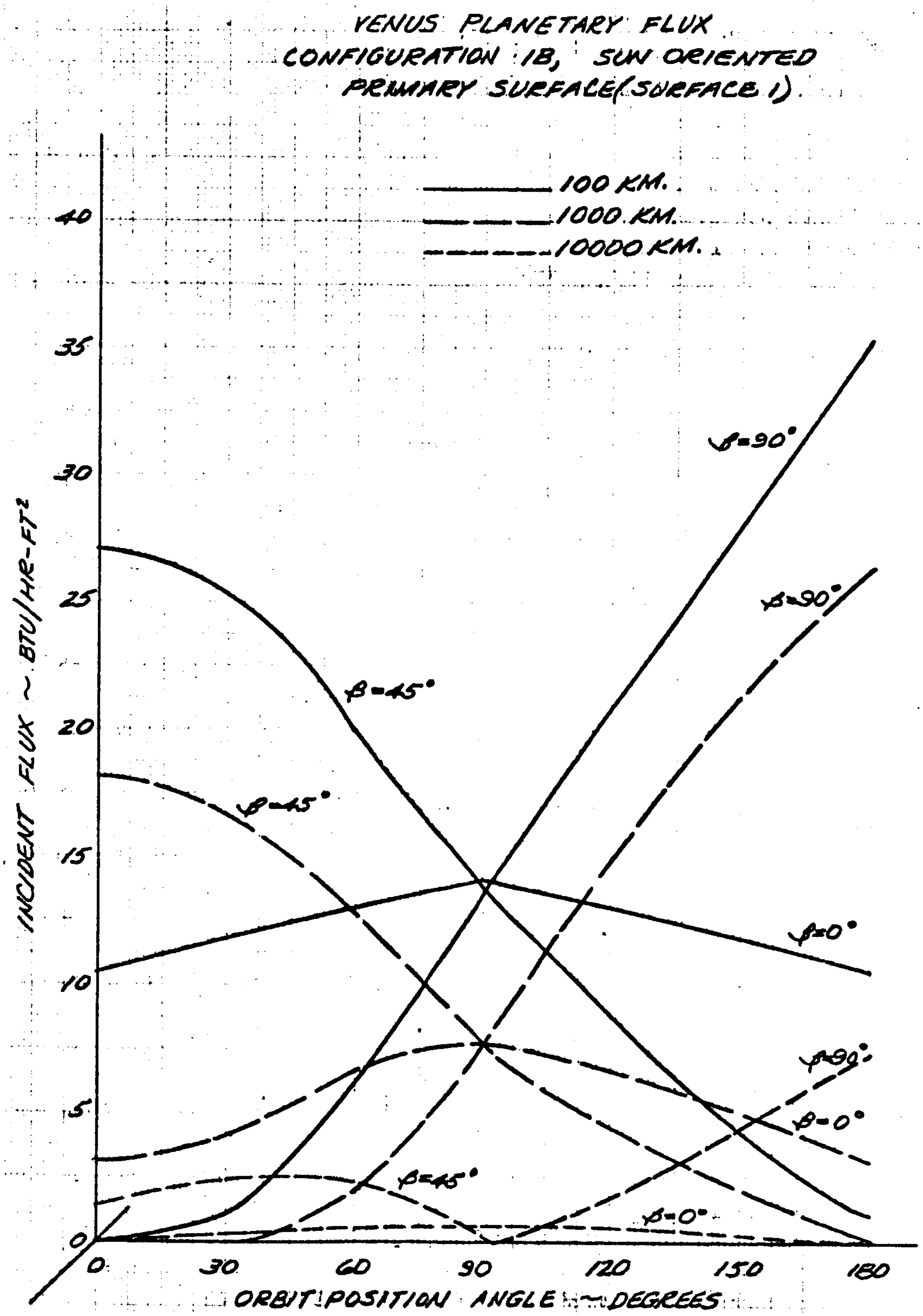


Fig. G-3 Venus Planetary Flux Configuration 1B
Sun Oriented

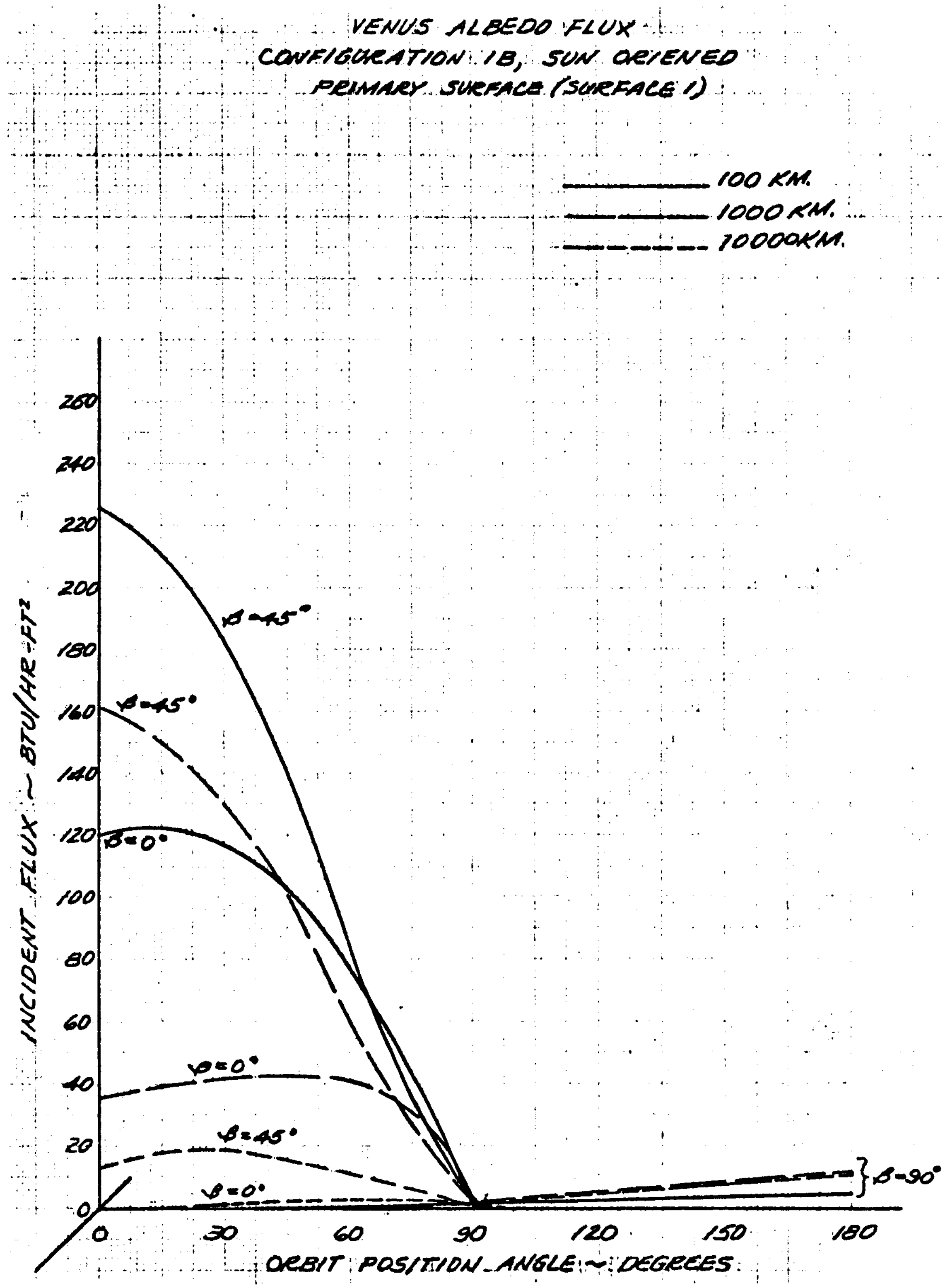


Fig. G-4 Venus Albedo Flux Configuration 1B
Sun Oriented

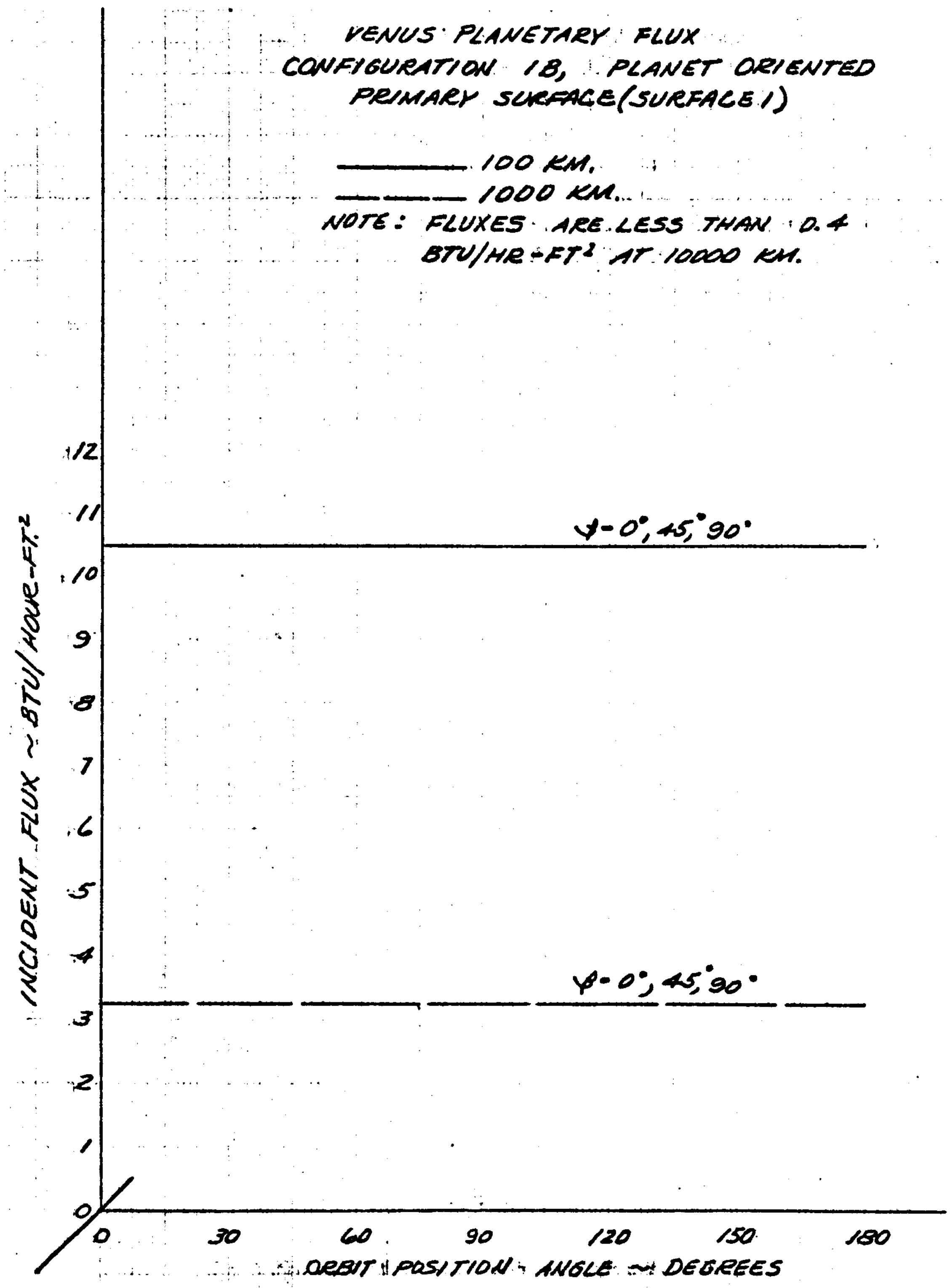


Fig. G-5 Venus Planetary Flux Configuration 1B
Planet Oriented

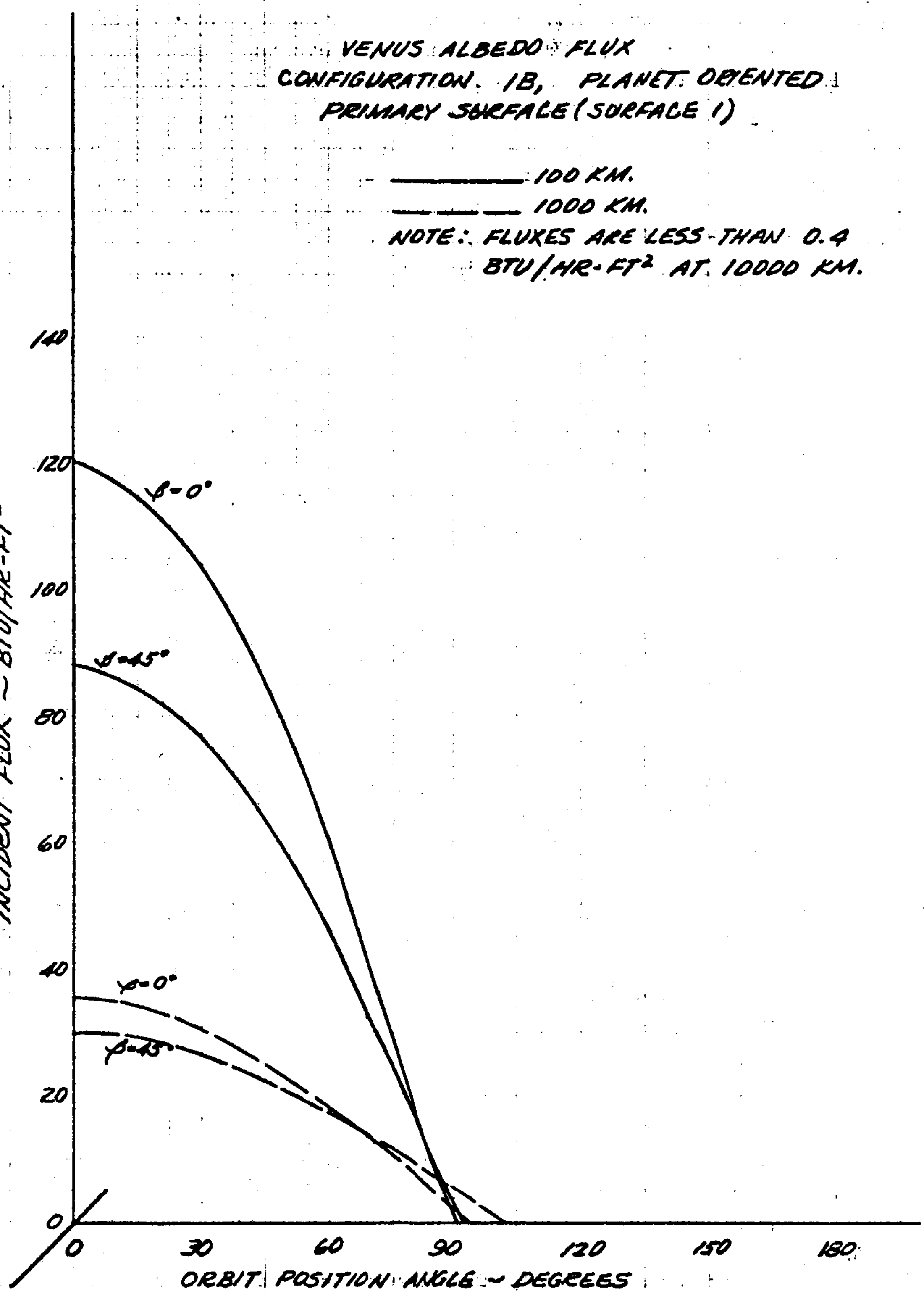


Fig. G-6 Venus Albedo Flux Configuration 1B
Planet Oriented

Appendixes G and H
PRESENTATION OF RESULTS

The parametric study results are listed three points per page. The data for each point are grouped in five blocks: HEAT FLUX block, VIEW FACTORS block, RAD. CONSTS.-SOLAR + REFLECTED block, RAD. CONSTS.-PLANETARY block, and POINT IDENTIFICATION block:

HEAT FLUX block: The heat fluxes to each surface are listed across the top of each point. The left-hand column is the surface identification number. The fluxes to each surface are listed from left to right in the following order:

1. QS(I) = direct incident solar flux
2. QS(A) = total absorbed solar flux
3. QR(I) = direct incident albedo flux
4. QR(A) = total absorbed albedo flux
5. QP(I) = direct incident planetary flux
6. QP(A) = total absorbed planetary flux

NOTE: The values of the fluxes, view factors, and radiation constants are listed in "floating point" form. Each number consists of a fraction and an exponent with a power of ten by which the fraction is multiplied. For example, the number 0.13918E 02 represents $0.13918 \times 10^{+02}$ or 13.918. Similarly, the number 0.78650E-01 is 0.78650×10^{-01} or 0.078650.

VIEW FACTORS block: The view factors between sun, planet, and two (or three) surfaces are listed in an array just below the heat fluxes. The symbols at the top of each column, and the left of each row identify the surface: S = sun, P = planet, 1 = surface 1, 2 = surface 2, 3 = surface 3. The number at the intersection of a row and column is the view factor from the surface at the left of the row to the surface at the top of the column.

RAD. CONSTS. - SOLAR + REFLECTED block: The radiation constants ($\mathcal{F}A$) for solar and albedo radiation are listed at the bottom left of each point. The arrangement in columns and rows is the same as the view factor arrangement (the column identification symbols have been omitted to conserve space). The S row (or column) contains the radiation constants for solar radiation, and is used in computing the net direct radiant interchange between the sun and the surfaces assuming no reflection from the planet. The P row (or column) contains the radiation constants for albedo radiation, and is used in computing the net radiant interchange between the sun and the surfaces through reflection from the planet. The S-S, S-P, and P-P quantities represent the flux reflected by the surfaces back onto the sun or planet. They may generally be ignored. The area in the $\mathcal{F}A$ expressions is based on a "b" dimension on surface 1 of 4 ft.

RAD. CONSTS. - PLANETARY block: The radiation constants ($\mathcal{F}A$) for planetary radiation are listed at the bottom right of each point. The arrangement in columns and rows is the same as the view factor arrangement (the column identification symbols have been omitted to conserve space). The S row and column are blank because there is no planetary radiation from the sun. The P row (or column) contains the radiation constants for planetary radiation, and is used in computing the net radiant interchange between the planet and the surfaces. The P-P quantity represents the planetary flux reflected by the surfaces back onto the planet. The area in the $\mathscr{F}A$ expressions is based on a "b" dimension on surface 1 of 4 ft.

POINT IDENTIFICATION block: The upper right-hand corner of each point contains the identification of the point. Each point is identified as follows:

- PLANET - VENUS or MARS. Identifies the planet for which the data are computed.

- ALTITUDE - 100 km, 300 km, 500 km, 1000 km, 3000 km, 5000 km, 10,000 km or 30,000 km. Indicates the altitude of the satellite above the mean planet surface.

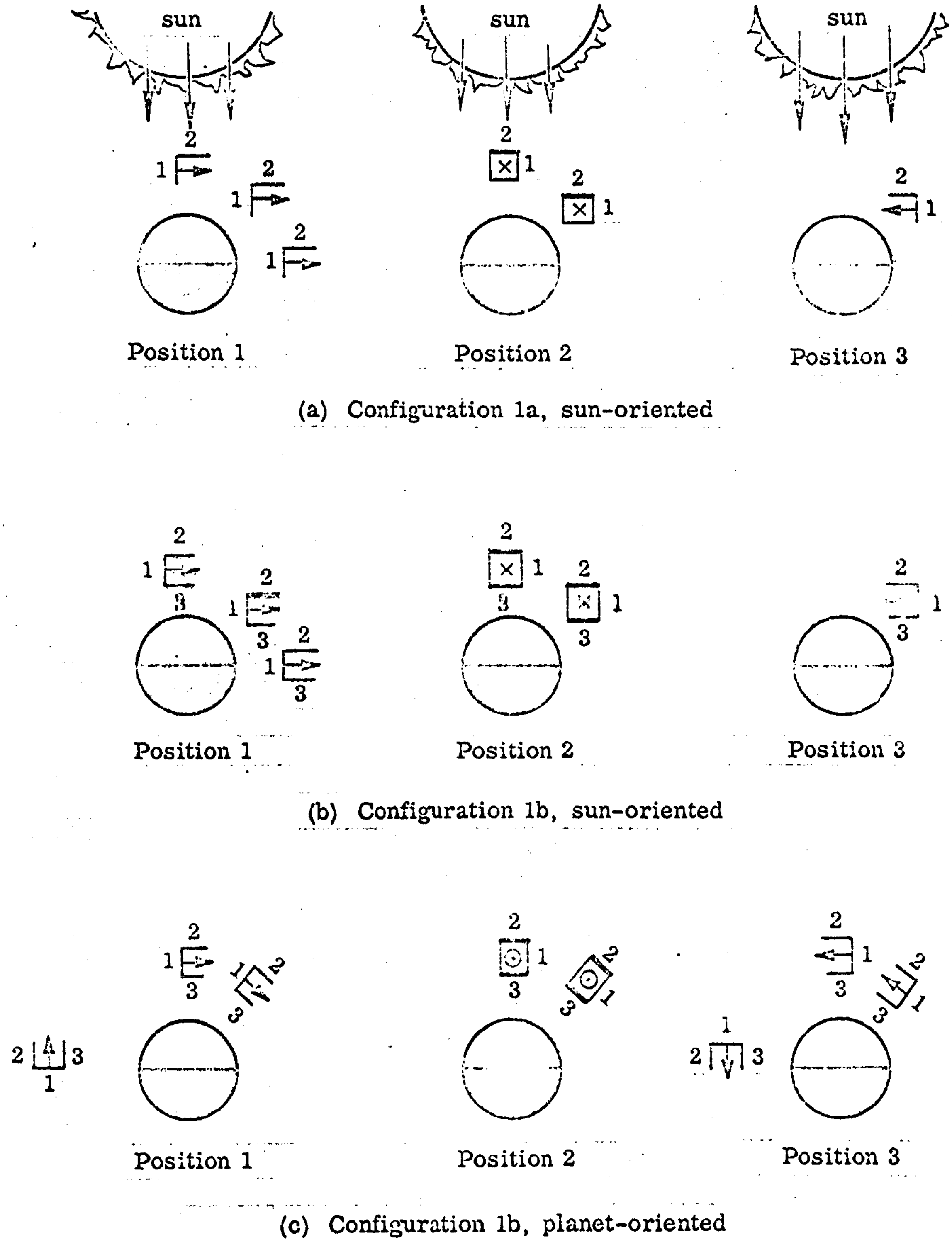
- ORBIT - NOON POLAR, 45 D POLAR, or TWI. POLAR. Indicates the satellite orbit. The NOON POLAR orbit crosses directly over the planet subsolar point. The 45 D POLAR orbit crosses the illuminated side of the planet midway between the subsolar point and the terminator. The TWI. POLAR orbit is directly over the terminator.

- ORIENTATION - SUN or PLANET. SUN indicates that surface 1 is oriented parallel to the rays of the sun, with surface 2 normal to the rays on the side toward the sun. PLANET indicates that surface 1 is perpendicular to the planet's surface, with surface 2 parallel to the planet's surface on the side away from the planet.

- CONFIGURATION - 1A or 1B. Configuration 1A consists of two surfaces with surface 2 extending at a right angle from one edge of surface 1. Configuration 1B consists of three surfaces with surface 2 extending at a right angle from one edge of surface 1, and surface 3 extending at a right angle from the opposite edge.

- POSITION - 1, 2, or 3. Indicates the direction surface 1 faces. With the satellite traveling north-to-south over the illuminated side of the planet, POSITION 1 indicates that surface 1 is facing west, POSITION 2 indicates that surface 1 is facing south in the SUN orientation or north in the PLANET orientation, and POSITION 3 indicates that surface 1 is facing east. (See Fig. G/H-1)

- ORBIT POSITION - Positions 1 through 8. Indicates the orbital location of the satellite. Position 1 is directly over the north pole of the planet; Position 2 is 60° north of the



LEGEND: → Unit normal to surface 1 in plane of paper
× Unit normal to surface 1 into paper
⊙ Unit normal to surface 1 out of paper

NOTE: View is looking down on north pole at planet. Surfaces are shown at orbit Position 4

Fig. G/H-1 Position and Orientation.

equator on the illuminated side of the planet; Position 3 is 30° north; Position 4 is over the equator; Position 5 is 30° south; Position 6 is 60° south; Position 7 is over the South Pole; and Position 8 is over the equator on the dark side of the planet. Note that the sun is assumed to be located over the equator so that the planet's north and south poles are located on the terminator.

- SURFACE 1 2 3 - The remainder of the identification block identifies the dimensions and radiation properties of the surfaces. The data is displayed in three columns: column 1 referring to surface 1, column 2 to surface 2, and column 3 to surface 3. (Configuration 1A consists of only two surfaces, so column 3 is filled with zeros.)

- A/B, C/B - Specifies the dimension ratios of the three surfaces: a/b for surface 1 in column 1, c/b for surface 2 in column 2, and c/b for surface 3 in column 3. (See Fig. G/H-2)

ABSORP. - The solar absorptivity of the three surfaces.

EMISS. - The infrared emissivity of the three surfaces.

ALPHA - The trapezoid angle (see Fig. G/H-2) of surfaces 2 and 3.

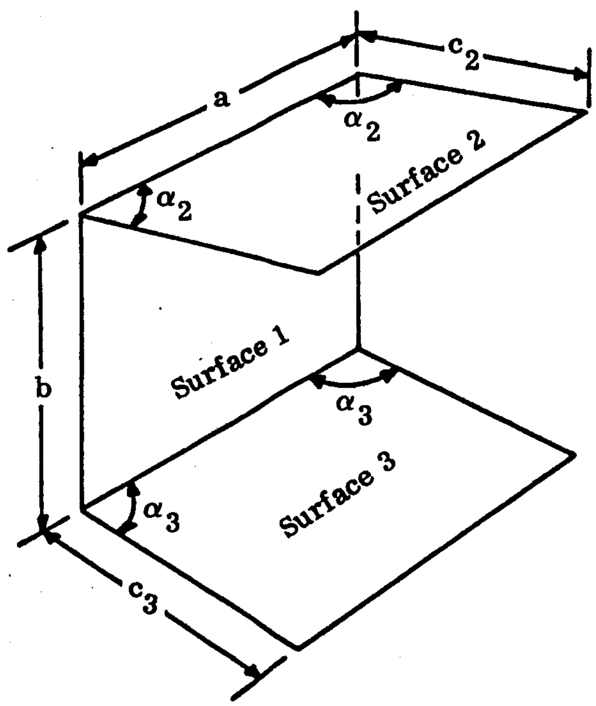


Fig. G/H-2 Surface Dimensions

Appendix H
PARAMETRIC STUDY RESULTS FOR MARS

H.1 PLANET MARS, CONFIGURATION 1A, SUN ORIENTED (Figs. H-1 and H-2)

H.1.1 NOON orbit

<u>Position 1</u> (192 pgs)

- 8 orbit positions
- 8 altitudes/orbit position
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

H.1.2 45 Degree orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 3</u> (192 pgs)

Same as Position 1; para. H.1.1

H.1.3 TWILIGHT orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

H.1.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

<u>Vary (α_s/ε) ratios</u> (48 pgs)

- 4 (α_s/ε) ratios, surface 1
- 4 (α_s/ε) ratios, surface 2/(α_s/ε) ratio, surface 1
- 3 (a/b) ratios/(α_s/ε) ratio, surface 2
- 3 (c/b) ratios/(a/b) ratio

<u>With α = 120° (surface 2 a trapezoid)</u> (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1203 pgs)

H.2 PLANET MARS, CONFIGURATION 1B, SUN ORIENTED (Figs. H-3 and H-4)

H.2.1 NOON orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

H.2.2 45 Degree orbit

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 3</u> (192 pgs)

Same as Position 1; para. H.1.1

H.2.3 TWILIGHT orbit

Position 1 (192 pgs)

Same as Position 1; para. H.1.1

H.2.4 At 1000 km, sub-solar point (NOON orbit, orbit position 4)

Vary c/b ratios separately (9 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios, surface 2/(a/b) ratio
- 3 (c/b) ratios, surface 3/(c/b) ratio, surface 2

Vary (α_s/ϵ ratios) (48 pgs)

- 4 (α_s/ϵ) ratios, surface 1
- 4 (α_s/ϵ) ratios, surfaces 2&3/(α_s/ϵ) ratio, surface 1
- 3 (a/b) ratios/(α_s/ϵ) ratio, surfaces 2&3
- 3 (c/b) ratios/(a/b) ratio

With α = 120° (Surfaces 2 and 3 trapezoids) (3 pgs)

- 3 (a/b) ratios
- 3 (c/b) ratios/(a/b) ratio

(1212 pgs)

H.3 PLANET MARS, CONFIGURATION 1B, PLANET ORIENTED (Figs. H-5 and H-6)

H.3.1 NOON orbit

Position 3 (192 pgs)

Same as Position 1; para. H.1.1

Position 2 (192 pgs)

Same as Position 1; para. H.1.1

H.3.2 45 Degree orbit

<u>Position 3</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 2</u> (192 pgs)

Same as Position 1; para. H.1.1

<u>Position 1</u> (192 pgs)

Same as Position 1; para. H.1.1

H.3.3 TWILIGHT orbit, orbit position 4

<u>Position 1</u> (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

<u>Position 3</u> (24 pgs)

- 8 altitudes
- 3 (a/b) ratios/altitude
- 3 (c/b) ratios/(a/b) ratio

(1008 pgs)

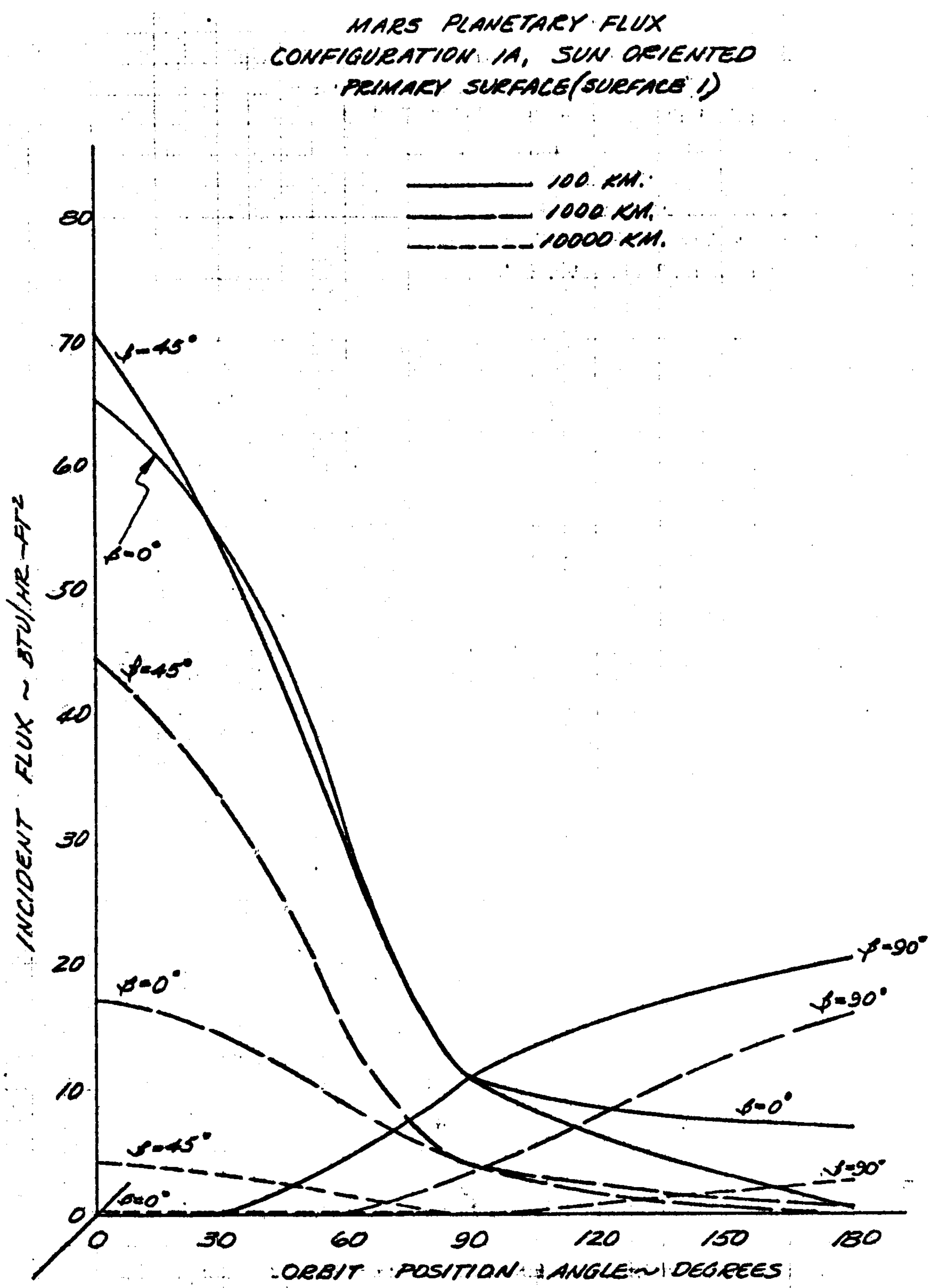


Fig. H-1 Mars Planetary Flux Configuration 1A
Sun Oriented

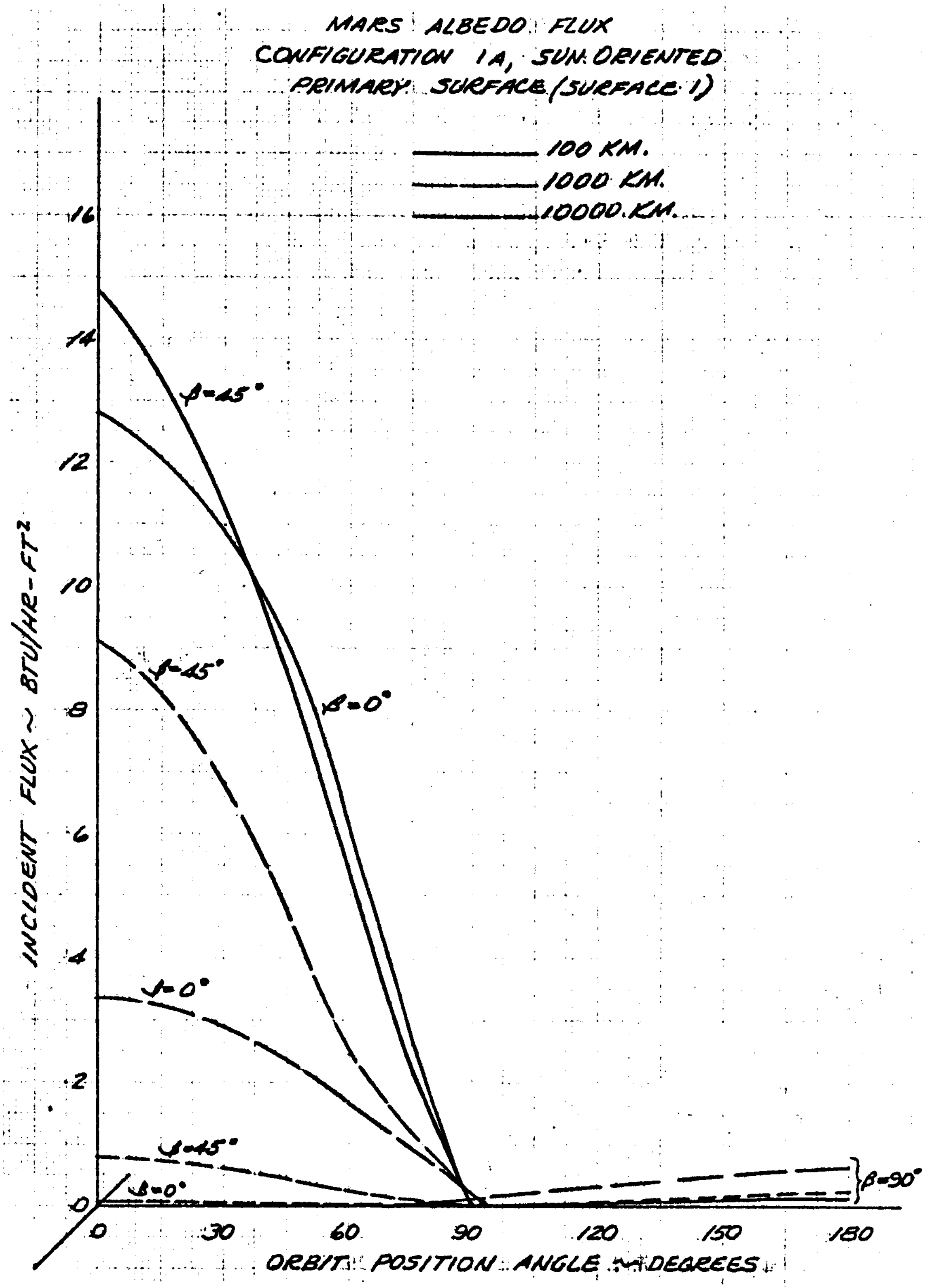


Fig. H-2 Mars Albedo Flux Configuration 1A
Sun Oriented

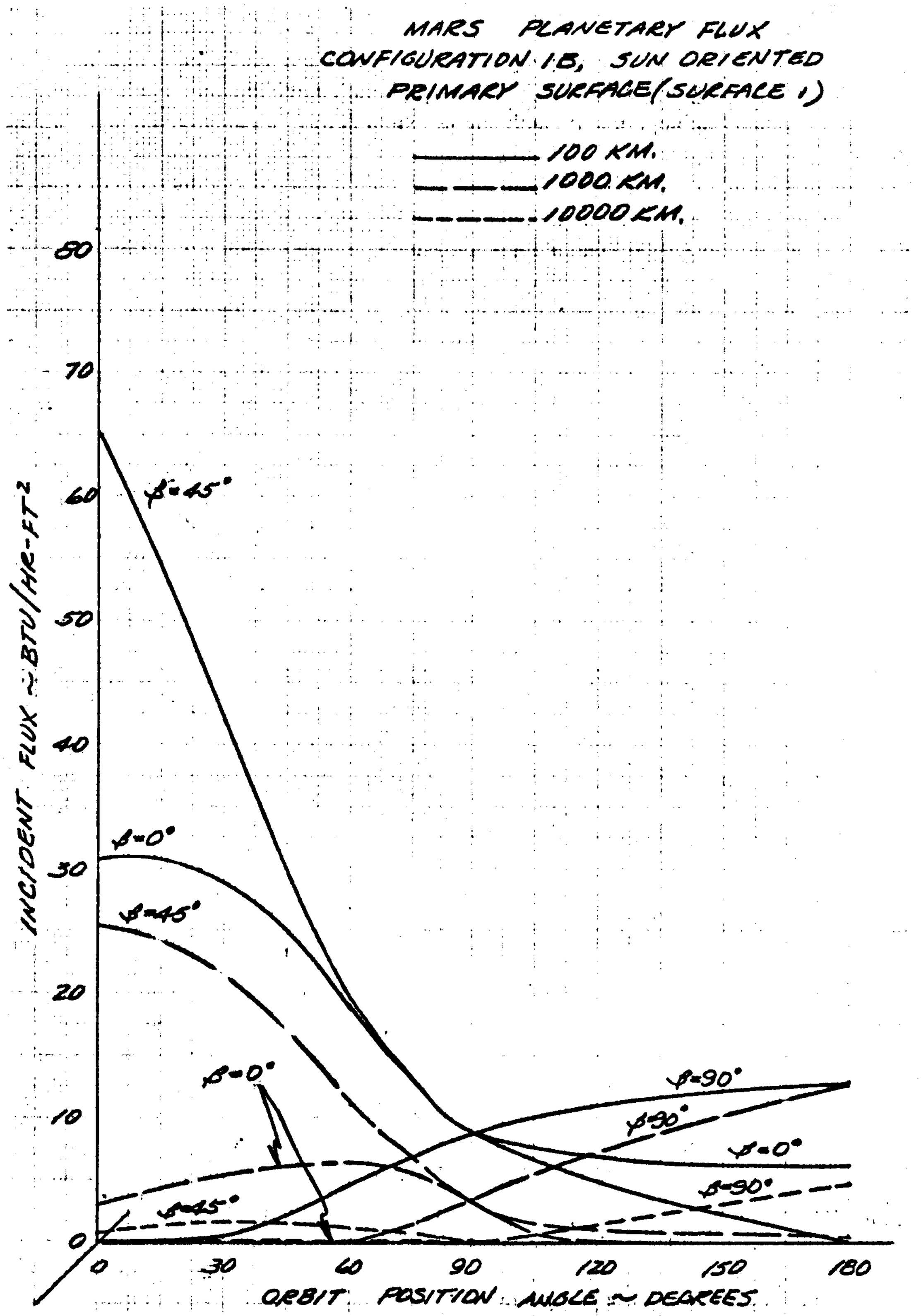


Fig. H-3 Mars Planetary Flux Configuration 1B
Sun Oriented

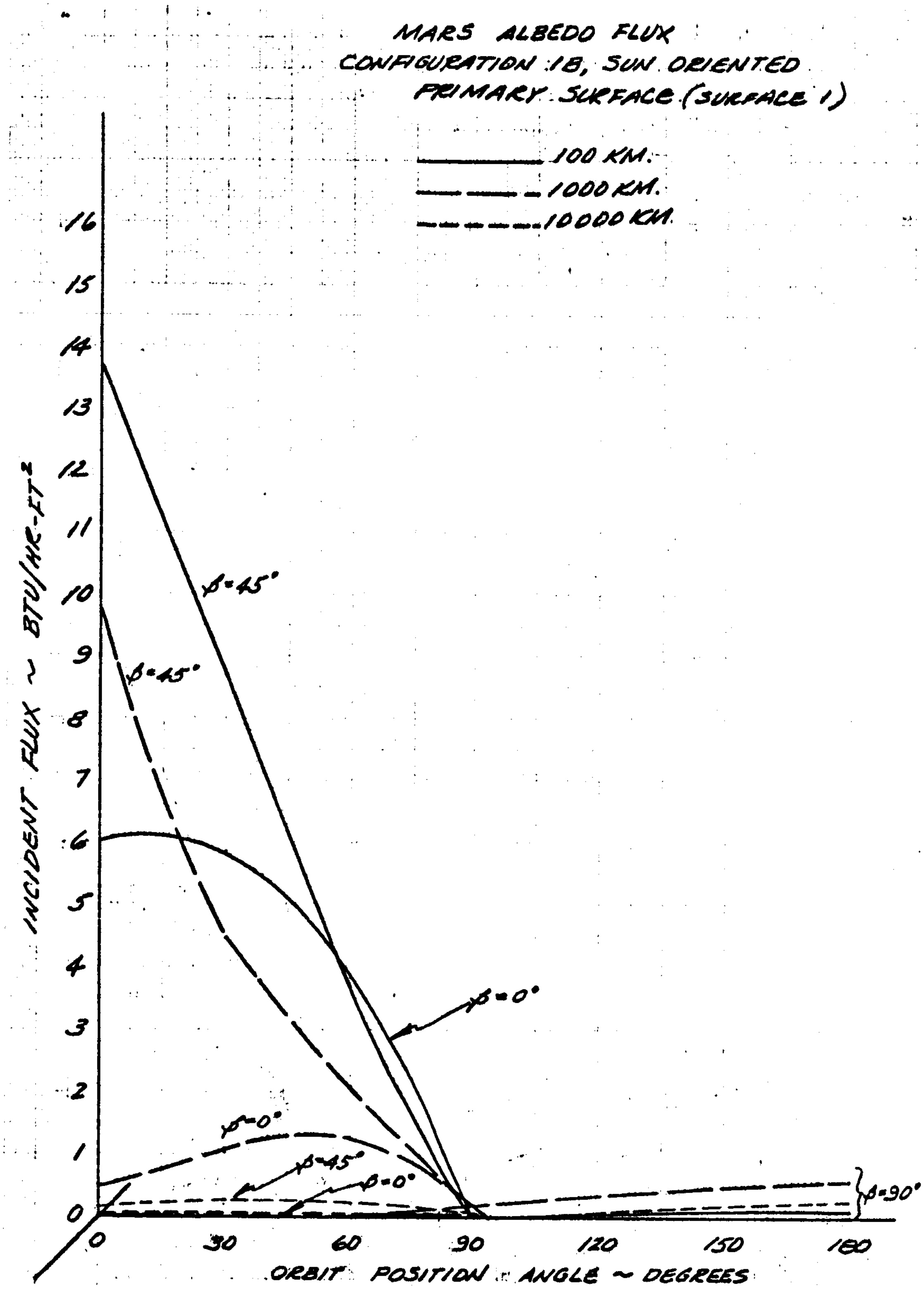


Fig. H-4 Mars Albedo Flux Configuration 1B
Sun Oriented

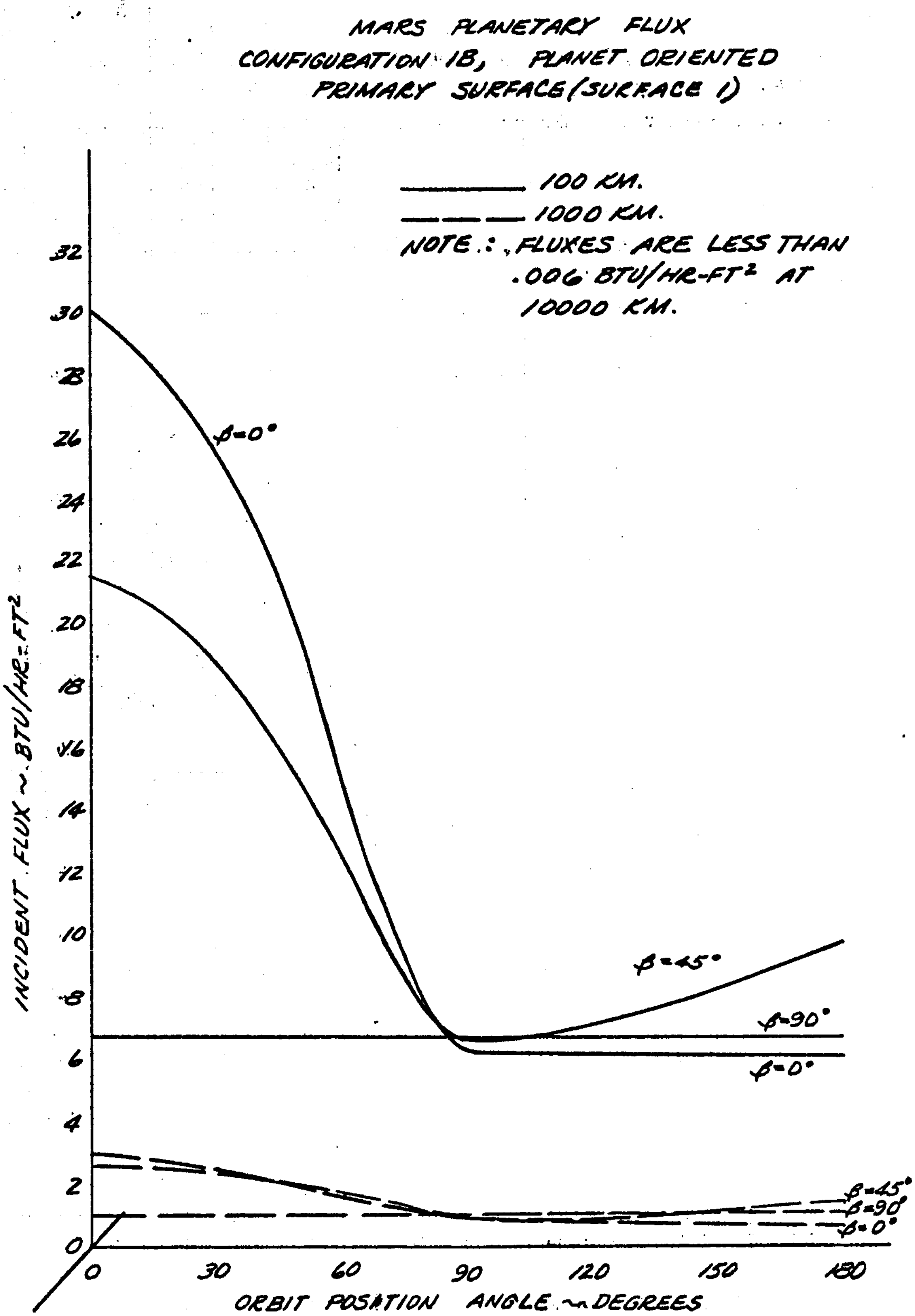


Fig. H-5 Mars Planetary Flux Configuration 1B
Planet Oriented

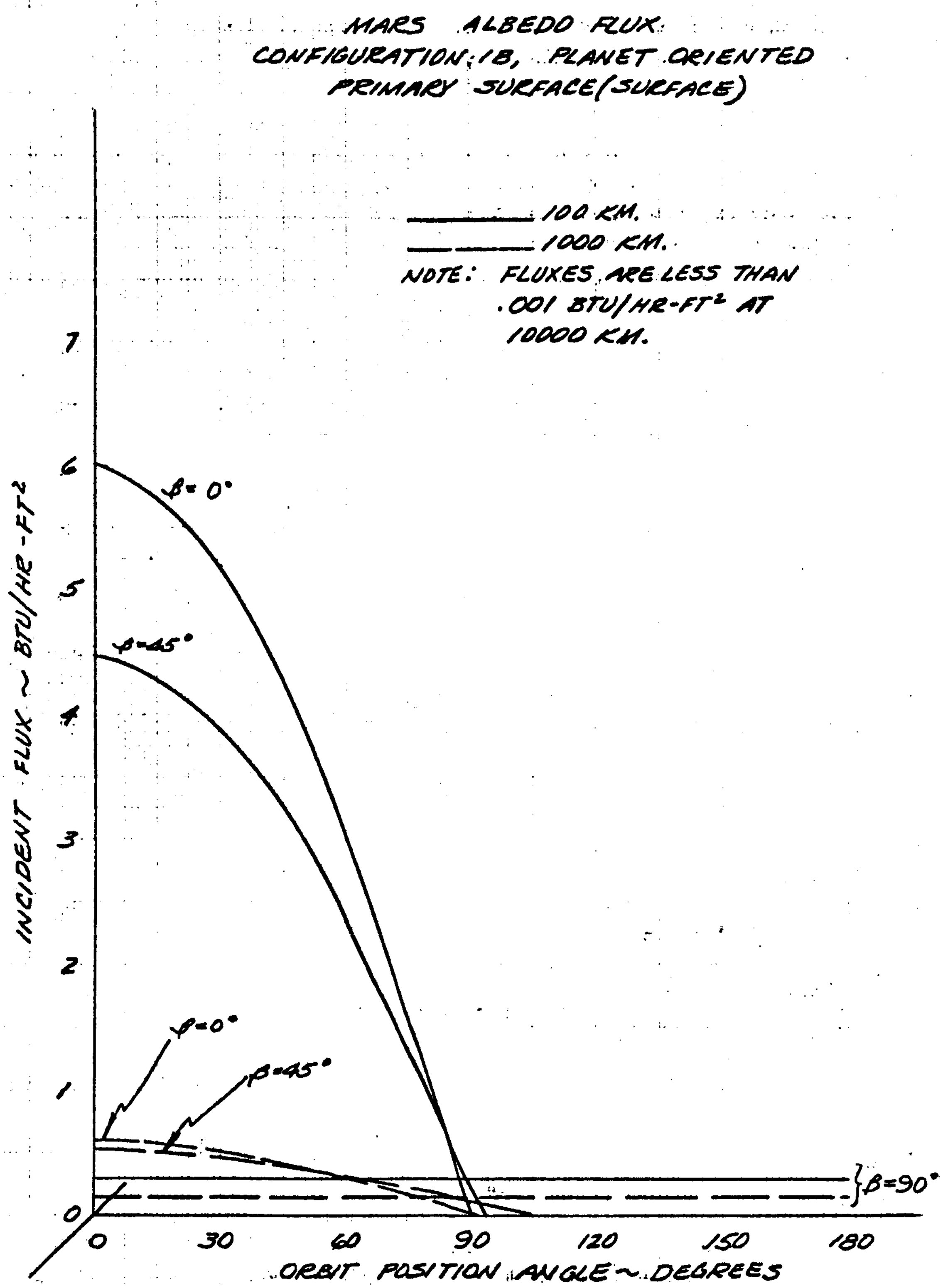


Fig. H-6 Mars Albedo Flux Configuration 1B
Planet Oriented

HEAT FLUX STUDY

ERRATA

1. Page 3-3, paragaph 2, line 5: Change "absorbed by each satellite surface from..." to "absorbed by each satellite surface including...".

2. Page 3-4, line 1: Change "...360 geocentric degrees. The" to "...360 geocentric degrees beyond the starting point. The".

3. Page 4-1, last paragraph, line 1: Change "Albedo Flux. The albedo flux accounted..." to "Albedo Flux. The albedo flux accounts...".

4. Page 4-1, last paragraph, line 3: Change "flux is accounted for..." to "flux accounts for...".

5. Page 4-5, Figure 4-1: The angle between surface 1 and surface 2 labeled "q" should be labeled "φ".

6. Page 4-5, legend: Delete "(surface)".

7. Page 5-7, line 7: Change "the FA matrix and the RADK factor, which is σFA..." to "the $\mathcal{F}$A matrix and the RADK factor, which is $\sigma\mathcal{F}$A...". (Script F's instead of block F's.)

8. Page A-2: Replace page A-2 with the attached page A-2.

9. Page A-4: Replace page A-4 with the attached page A-4.

10. Page A-5: Replace page A-5 with the attached page A-5.

11. Pages A-7 and A-8, paragraph A.1.4, The True Elliptical Orbit Equations: Change the equations for semimajor axis, eccentricity, orbit period, eccentric anomaly, and time from periapsis to read as follows:

    Semimajor axis, radius, $A = (RA + RP + 2R_o)/2$

    Eccentricity, $E = (RA - RP)/2A$

    Orbit Period, $P = 2\pi\sqrt{A3/R_o^2\, g_o}$

    Eccentric Anomaly, $EG = \cos^{-1}\dfrac{A-R}{AE}$

    Time from Periapsis, $T = P/2\pi\,[EG - E\sin EG]$

12. Page A-12, Figure A-10: Change "ILK = $\underline{+}$: DISK" to "ILK = $\underline{+}$2: DISK".

13. Page A-17, the P(I,J) equations: Change the equations for P(2,2) and P(2,3) to read:

    $P(2,2) = \cos\omega_s \times \cos\varphi_s + \sin\omega_s \times \sin\gamma_s \times \sin\varphi_s$

    $P(2,3) = \sin\omega_s \times \cos\varphi_s + \cos\omega_s \times \sin\gamma_s \times \sin\varphi_s$

14. Page A-18, line 1: Change "ILK = ±1 (Disk)" to "ILK = ±2 (Disk)".

15. Page A-31, line 1 of NOTE: Change "NOTE. The above absorbed fluxes are on a per unit bases..." to "NOTE. The above absorbed fluxes are on a per unit area basis...".

16. Page A-32: In column headed "Code", add "J" to line reading "DATA(J)... Surface identification...".

17. Page A-32: In column headed "Code", add "K" to line reading "DATA(K)... Location of parameters...".

18. Page A-32: In column headed "Symbol", change "DATA(J)" to "DATA(J,K)".

19. Page A-32: In column headed "Symbol", delete "DATA(K)".

20. Page A-34, last line: Change "J and K A 3 x 3 matrix, I = 22" to "J and K A 3 x 3 matrix, I = 1 to 22".

21. Page A-36, next-to-last entry in "Symbol" column: Change "KLUXS(J,K)" to FLUXS(J, K)".

22. Page B-13, paragraph 2, line 1: Change "The PERCENT ERROR indicates the finite difference..." to "The PERCENT ERROR indicates the maximum error in the finite difference...".

23. Page B-14, last line: Change " α_{min} = ... the α direction" to " τ_{min} = ... the τ direction".

24. Page B-15, Card 2: Add "±" in column 52. (DELTA may be + or -.)

25. Page B-15, Card 7: Change label of third field (columns 13-15) from "NO" to "N τ ".

26. Page B-15, last card: Change description of "VARIABLES" field from:

VARIABLES
0 (NOTHING)
MAXIMUM
ORBIT ECCENTRICITY
...
RADIATION CONSTANTS, $\sigma \mathcal{F}_{i-j} A_i$

to:

VARIABLES
0 (NOTHING)
1 MAXIMUM SOLAR FLUX (SOLAR CONSTANT)
ORBIT ECCENTRICITY
...
RADIATION CONSTANTS, $\sigma \mathcal{F}_{i-j} A_i$

27. Page B-17, Figure B-8: Change "γ_{max}" to "β_{max}" so that β_{min} and β_{max} indicate the radius vectors and γ_{min} and γ_{max} indicate the angles.

28. Page B-18, first line: Change "α_{max} =...the α direction" to "γ_{max} =... the γ direction".

29. Page B-20, first paragraph following "ω =...", lines 2, 3, 5, and 10: Change "NVα" to "NVγ".

30. Page B-20, first paragraph following "ω =...", line 10: Change "...the α direction" to "... the γ direction".

31. Page B-20, second paragraph following "ω =...", line 2: Change "Nα" to "Nγ".

32. Page B-20, second paragraph following "ω =...", line 5: Change "Nα =...the α direction" to "Nγ =...the γ direction".

33. Page B-20, next-to-last line: Change "... α direction = (α_{max} - α_{min})/NVα" to "... γ direction = (γ_{max} - γ_{min})/NVγ".

34. Page B-22, first line: Change "... α direction = g/Nα" to "... γ direction = g/Nγ".

35. Page B-22, paragraph 2, line 1: Change "..., NVα = 3, ..., Nα = 6..." to "..., NVγ = 3,..., Nγ = 6...".

36. Page B-22, paragraph 2, line 2: Change "...NVα = 12" to "...NVγ = 12".

37. Page B-22, paragraph 2, line 3: Change "...Nα = 30" to "...Nγ = 30".

38. Page B-22, paragraph 2, line 4: "...(Nβ times Nα)(NVβ times NVα)" to (Nβ times Nγ)(NVβ times NVγ)".

39. Page B-25: Replace page B-25 with the attached page B-25.

40. Page C-4, paragraph "d.": Insert paragraph heading "e. Delta Angle" between lines 2 and 3.

41. Page C-7, last line of "<u>Block 4</u>": Change "963" to "324".

42. Page C-8, paragraph 4, line 2: Change"...ecliptic, the -X" to "...ecliptic, the -Y".

43. Page C-12: Replace page C-12 with the attached page C-12.

44. Page D-5, Figure D-4: Replace page D-5 with the attached page D-5.

45. Page D-7, Figure D-5: Replace page D-7 with the attached page D-7.

46. Page D-9, Figure D-6: Replace page D-9 with the attached page D-9.

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47. Page E-3: Delete cards 083 through 090, and insert cards R083 through R090 as follows:

```
      ANUMB=CØSF(DELTA)                                      R083
      BNUMB=SINF(DELTA)                                      R083A
      CNUMB=CØSF(C)                                          R083B
      DNUMB=SINF(C)                                          R083C
      FNUMB=SINF(D)                                          R083D
      GNUMB=ACØSF(ANUMB*DNUMB*FNUMB-BNUMB*CNUMB)             R083E
      BETA=90.-GNUMB                                         R083F
      HNUMB=SINF(GNUMB)                                      R083G
      IF(HNUMB)34,33,34                                      R083H
   33 THE=ALPHA                                              R083I
      GØ TØ 15                                               R083J
   34 ENUMB=CØSF(D)                                          R083K
      THE=ACØSF((ANUMB*ENUMB)/HNUMB)                         R084
      ENUMB=(ANUMB*CNUMB*FNUMB+BNUMB*DNUMB)/HNUMB            R085
      IF(ENUMB)36,37,37                                      R086
   36 THE=360.-THE                                           R087
   37 THE=THE+ALPHA                                          R088
      IF(THE-360.)15,38,38                                   R089
   38 THE=THE-360.                                           R090
```

48. Page E-9: Delete the DIMENSIØN and CØMMØN statements:

```
      DIMENSIØN DATA (22,16),LDATA (22,16),DM1 (9409),P(22,3,3),R(3),
    1 DM2(2),A(3),NTN(57)
      CØMMØN DATA, DM1,P,R,NS,DM2,IZ,IK,A,NV,NTN,RAD,PI,DCR,RPLAN
```

and insert the DIMENSIØN and CØMMØN statements:

```
      DIMENSIØN DATA (22,16),LDATA(22,16)PØS(1000,3),ARA(1000,3),      R
    1 DM1(3409),P(22,3,3),R(3),DM2(2),A(3),NTN(57)                     R
      CØMMØN DATA, PØS,ARA,DM1,P,R,NS,DM2,IZ,IK,A,NV,NTN,RAD,PI,DCR,   R
    1 RPLAN                                                            R
```

49. Page E-10: Delete card 029:

```
   11 LDATA(2,2)=I                                                     029
```

and insert cards R029 through R029V:

```
   11 IF(IZ)12,12,19                                                   R029
   12 IF(I-LDATA(2,2))13,20,15                                         R029A
   13 NPN=36*(I-LDATA(2,2))                                            R029B
      NP1=NTN(37)+1                                                    R029C
      NP2=NTN(NV)                                                      R029D
      DØ14J=NP1,NP2                                                    R029E
      J1=J+NPN                                                         R029F
      DØ14K=1,3                                                        R029G
      PØS(J1,K)=PØS(J,K)                                               R029H
   14 ARA(J1,K)=ARA(J,K)                                               R029I
      GØ TØ 17                                                         R029J
   15 NPN=36*(I-LDATA(2,2))                                            R029K
```

```
      NP1=NTN(37)+1                                              R029L
      NP2=NTN(NV)                                                R029M
      DØ16J=NP1,NP2                                              R029N
      J1=NP2+1-J                                                 R029Ø
      J2=J1+NPN                                                  R029P
      DØ16K=1,3                                                  R029Q
      PØS(J2,K)=PØS(J1,K)                                        R029R
16    ARA(J2,K)=ARA(J1,K)                                        R029S
17    DØ18J=38,NV                                                R029T
18    NTN(J)=NTN(J)+NPN                                          R029U
19    IDATA(2,2)=I                                               R029V
```

50. Page E-7: Delete cards 267 through 281, and insert cards R267 through R275 as follows:

```
                                                  R267
230  SB=ANGLE+ALPHA                               R268
     IF(SB-360.)238,236,236                       R269
236  SB=SB-360.                                   R270
238  ENUMB=CØSF(ØMEGA)                            R271
     GNUMB=CØSF(SB)                               R272
     HNUMB=SINF(SB)                               R273
     SS=DNUMB*HNUMB                               R274
     DING=GNUMB*FNUMB+HNUMB*ENUMB*CNUMB           R275
     BING=GNUMB*ENUMB-HNUMB*FNUMB*CNUMB
```

51. Generalized Heat Flux Study Source Program Deck: Remove the MAIN PROGRAM and SUBROUTINE VIEW, and replace with the accompanying modified versions of the MAIN PROGRAM and SUBROUTINE VIEW. The modified versions incorporate the changes listed above in items 47-50.

$$\beta = 90. - \cos^{-1}(\cos\delta \sin i \sin\Omega - \sin\delta \cos i)$$
$$\sin\theta_p = (\cos\delta \cos i \sin\Omega + \sin\delta \sin i)/\cos\beta$$
$$\cos\theta_p = \cos\delta \cos\Omega/\cos\beta$$
$$\alpha_s = 0 \qquad \text{if } \cos\beta = 0$$
$$= \alpha_p + \cos^{-1}(\cos\theta_p) \qquad \text{if } \sin\theta_p \geq 0$$
$$= \alpha_p + [360. - \cos^{-1}(\cos\theta_p)] \qquad \text{if } \sin\theta_p < 0$$

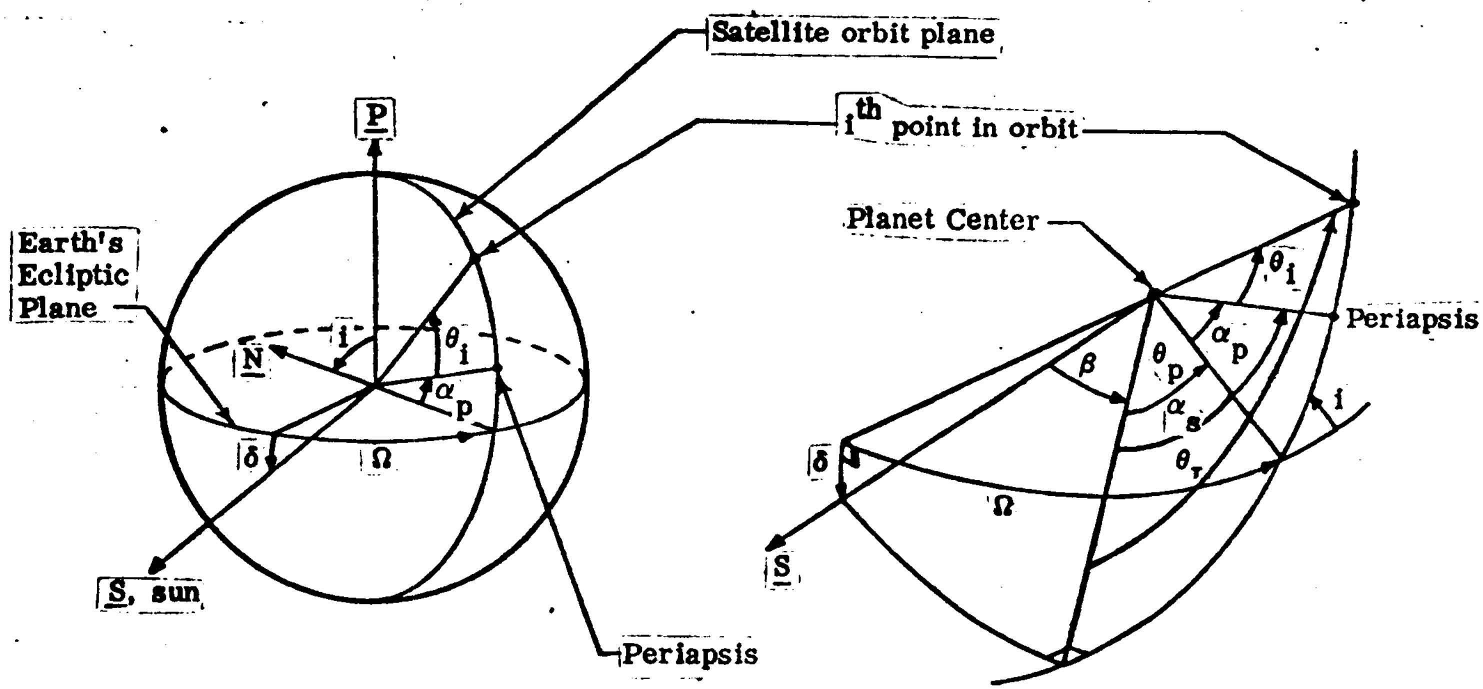

Fig. A-1 Orbit Plane

Fig. A-2 Orbit Plane Detail

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$$R(3,2) = \sin \omega_I \cos \psi_I$$

$$R(3,3) = \cos \omega_I \cos \psi_I$$

Then

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = [R] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

However, it is first necessary to define the +Z axis of the sun and the planet in terms of the X'' , Y'' , Z'' axis depending on the orientation of the satellite.

Planet-oriented satellite. The + Z axis is defined as follows:

Z_s = +Z axis of the sun for the i^{th} satellite position

Z_p = +Z axis of the planet for the i^{th} satellite position

$\theta_T = \alpha_s + \theta_i$ (see Fig. A-2)

$$Z_s = [-\sin \theta_T \cos \beta \ \sin \beta \ \cos \theta_T \cos \beta] \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

$$Z_p = Z''$$

Or, in terms of the X , Y , Z coordinate system,

$$Z_s = [-\sin \theta_T \cos \beta \ \sin \beta \ \cos \theta_T \cos \beta] \begin{bmatrix} R(1,1) & R(1,2) & R(1,3) \\ R(2,1) & R(2,2) & R(2,3) \\ R(3,1) & R(3,2) & R(3,3) \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Also,

$$Z_p = [R(3,1) \ R(3,2) \ R(3,3)] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

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<u>Space-oriented satellite.</u> The +Z axis is defined as follows:

$$Z_p = \left[\sin\sigma \;\; -\sin\Omega_T\cos\sigma \;\; \cos\sigma\cos\Omega_T\right]\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

$$Z_s = \left[-\sin\delta \;\; 0 \;\; \cos\delta\right]\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix}$$

Or, in terms of the X , Y , Z coordinate system;

$$Z_p = \left[(\sin\sigma)(-\sin\Omega_T\cos\sigma)\;(\cos\Omega_T\cos\sigma)\right]\begin{bmatrix} R(1,1) & R(1,2) & R(1,3) \\ R(2,1) & R(2,2) & R(2,3) \\ R(3,1) & R(3,2) & R(3,3) \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$Z_s = \left[-\sin\delta \;\; 0 \;\; \cos\delta\right]\begin{bmatrix} R(1,1) & R(1,2) & R(1,3) \\ R(2,1) & R(2,2) & R(2,3) \\ R(3,1) & R(3,2) & R(3,3) \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

A.1.3 Geocentric Angles of Shadow Points

As shown in Fig. A-6, a shadow point occurs when $\cos\alpha_1 + \cos Z_1 = 0$. These two unknown angles are found by an iterative process in the SHADOW subroutine.

From spherical trigonometry and identities, the following equation is developed and solved to determine the shadow points:

$$SZ = \cos(Z) = \cos\beta\cos\theta$$

$$90° < Z_1 < 270°$$

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PERCENT TIME IN THE SUN = 100.0                ALPHA(S) ANGLE =  321.9

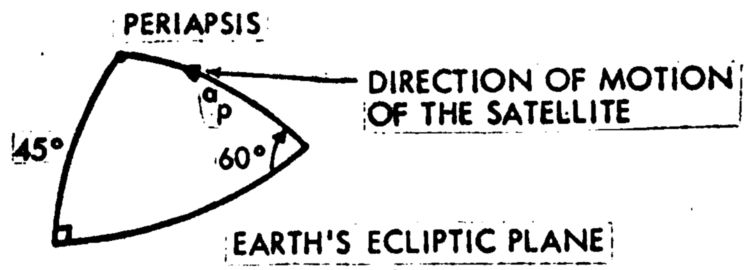
ORBIT ECCENTRICITY = C.0062                    BETA ANGLE =  -71.4

SOLAR CCNSTANT = 0.12312E-00

ORBIT PERIOC = 0.55125E 04

RADIATICN CONSTANTS FCR VEHICLE NODES.  SPACE = NUMBER 21
K( 1, 2) =  0.
K( 2, 3) =  0.
K( 1,21) =  0.45259E-12
K( 2,21) =  0.45259E-12
```

Fig. B-13 Variables Written Out



$$\sin \alpha_p = \sin 45° / \sin 60°$$

$$\text{or } \alpha_p = \sin^{-1}\left(\frac{.70711}{.86603}\right) = 54.8°$$

Fig. C-3 Alpha (p)

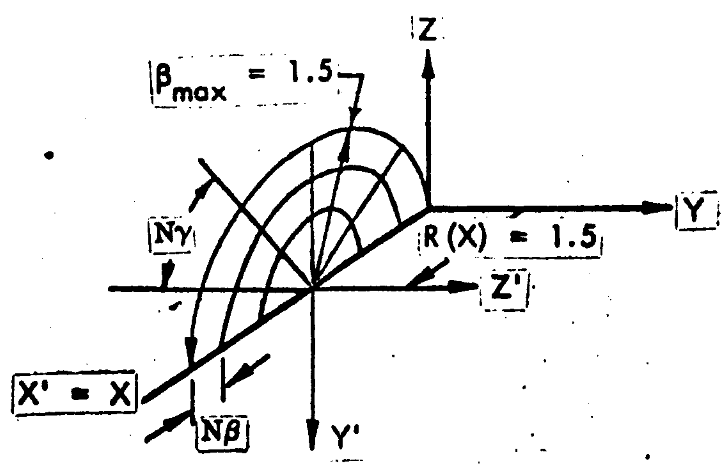


Fig. C-4 Disk

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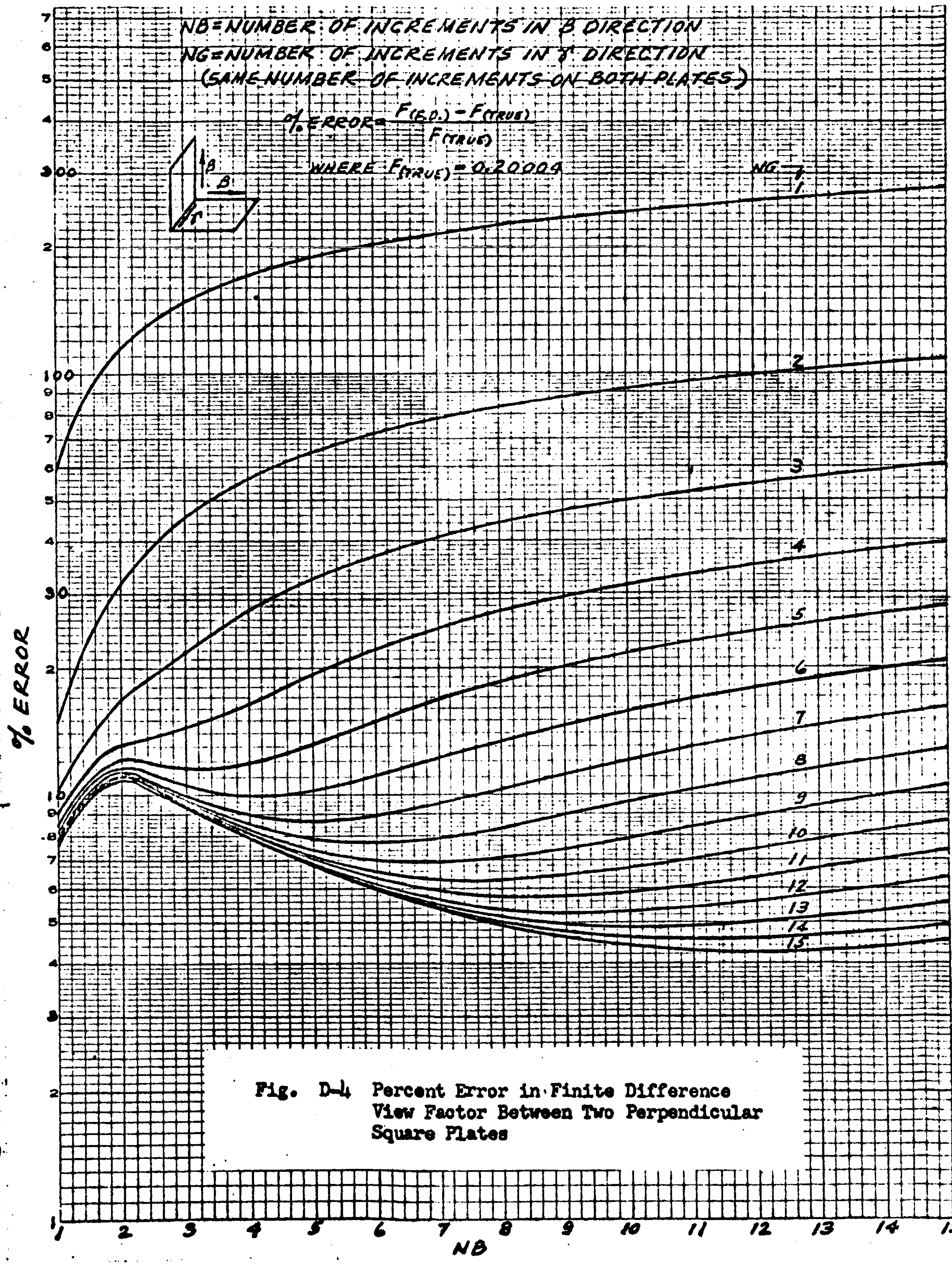

Fig. D-4 Percent Error in Finite Difference View Factor Between Two Perpendicular Square Plates

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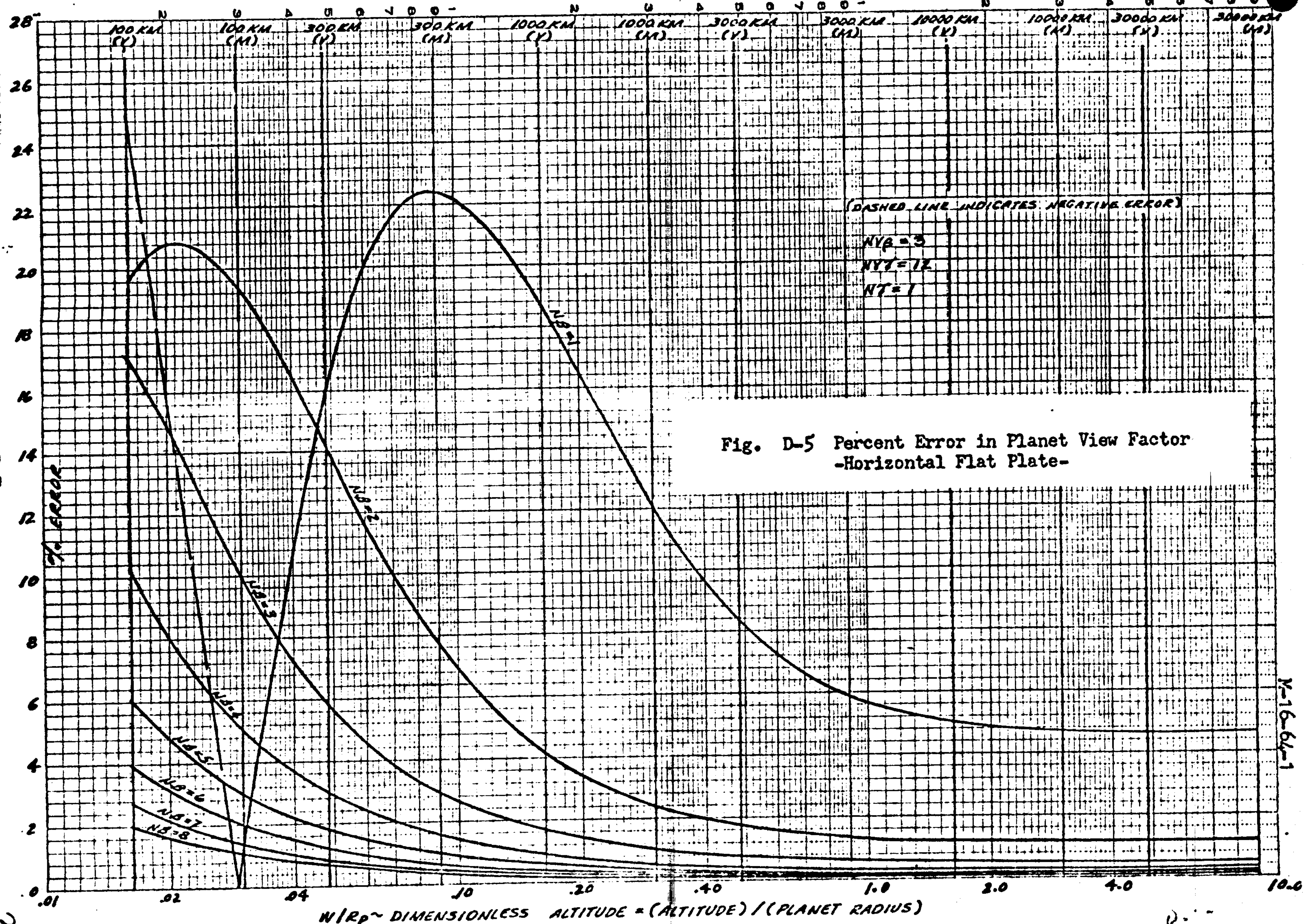

Fig. D-5 Percent Error in Planet View Factor
-Horizontal Flat Plate-

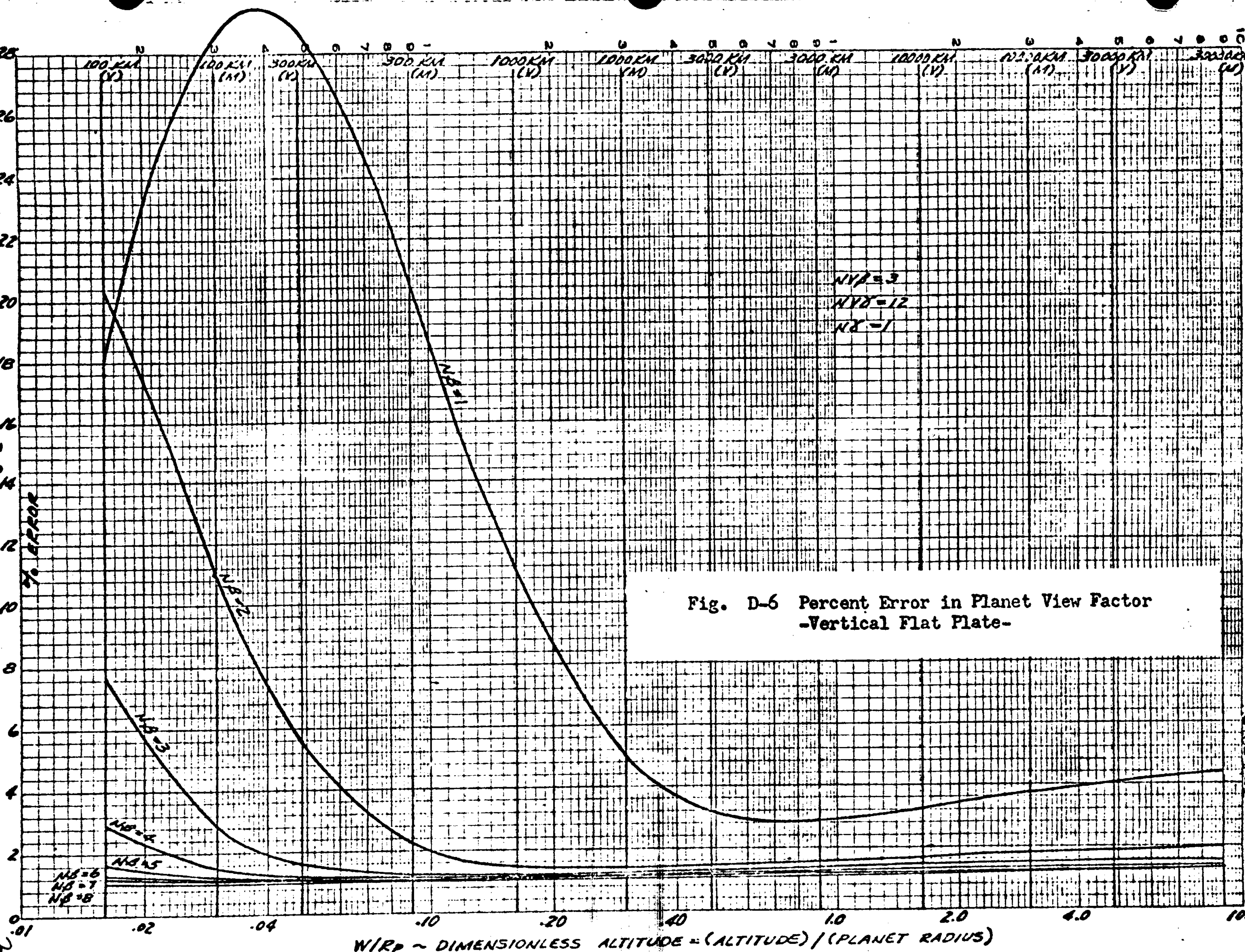

Fig. D-6 Percent Error in Planet View Factor
-Vertical Flat Plate-

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